
BOTANICAL STUDIES OF DISTURBED SITES
IN SUB-ARCTIC AND ARCTIC REGIONS

# Botanical Studies of Natural and Man-Modified Habitats in the Mackenzie Valley, Eastern Mackenzie Delta Region and the Arctic Islands



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The data for this report were obtained in part as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada.
While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.
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TABLE OF CONTENTS

Page

LIST OF TABLES AND FIGURES

## SUMMARY

These studies continue to show that the consequences of land use practices are quite different when comparing the northern boreal forest (Norman Wells area), the Low Arctic of the Tuktoyaktuk Peninsula and Prudhoe Bay, and the High Arctic within the Queen Elizabeth Islands. This is equally true when comparing upland and lowland sites within an area.

Soil and plant nutrient data collected along three transects of upland, midslope and depression sites at Tuktoyaktuk, Tununuk Point and Reindeer Station in the Caribou Hills show considerable differences in the magnitude and partition of nutrients. Generally, the soils are organic in the lowlands and gleysolic on slopes at all study sites. Brunisols occur in the best-drained areas at Tununuk Point. Organic matter thickness and soil water retention are greatest in lowlands and least on hilltops while the reverse holds for active layer depth, surface organic density and pH. Available and total soil nitrogen show no difference between uplands and lowlands, but available potassium and phosphorus are significantly greater on uplands. Standing crop and litter nitrogen, plant standing crop and litter are greatest in uplands and least in lowlands. In contrast with many ecosystems, these Low Arctic ones have a larger component of the nutrient pool in the surface organic layer than in the standing crop of plants or in the litter. If these nutrients are not retained by replacing the organic matter after construction projects, large amounts of fertilizer will be needed to replace these losses. In general, the soils are very low in available phosphorus and potassium with practically no available nitrogen. This stems from the slow rates of nutrient release from slow decomposition which is limited by cold soils. Nutrients, when available, are quickly utilized by plants and microorganisms.

The role of vegetation in the partition of solar radiation is quite different in the forest and in the tundra. The shrub tundra vegetation at Tuktoyaktuk plays a minor role in the energy budget, provided the organic surface mat is not disturbed. With winter road, fire, and oil spill disturbances, net radiation (Rn) increased (4 to 17 per cent) and albedo decreased (33 to 53 per cent). Latent heat of evaporation (LE) decreased most (38 percent) with an oil spill which impeded evaporation; reductions in LE were 23 per cent for both fire and winter road disturbances. Sensible heat flux (H) increased 50 per cent, 70 per cent, and 130 per cent respectively with fire, winter road, and oil spill disturbances. Soil heat flux (G) increased 56 per cent on the winter roads and 67 per cent on the oil spill plot, but only 33 per cent with burning. The peat surface had been left nearly intact by the fire, thus its importance in the partitioning of energy was demonstrated.

In the Boreal Forest approximately 60 per cent of total radiation is reflected or dissipated before it reaches the ground. Thus, forest removal has a more profound influence on energy dispersal. On a seismic line, with much of the peat surface intact, sensible heat flux remained the same but LE decreased by 16 per cent and G increased 125 per cent. Had the peat layer been removed, thermal input into the soil and depth of the active layer would have been even greater.

The potential for thermal subsidence in areas of ice-rich permafrost increases with increased complexity of the canopy structure so that land use planning within the northern Boreal Forest should carefully consider vegetation types in construction planning. Assuming drainage, soils and ice content of permafrost remain fairly constant, the clearing of forests will result in greater thermal changes than will the clearing of shrub or herb vegetation. The taller vegetation absorbs and re-radiates more energy than low vegetation. If trees are removed, an increased amount of energy must be dissipated by the surface layers as sensible heat of convection (H) or as soil heat flux (G).

Field research in 1970 showed that the native grasses *Arctagrostis latifolia* and *Calamagrostis canadensis* were the most important species invading surface disturbed areas east of the Mackenzie River Delta and in the scrubby forests near Inuvik. *Arctagrostis* is a true tundra species while *Calamagrostis* is near its northern limit of distribution at Tuktoyaktuk. Both species produce seed with a high viability, though more is generally produced by *Arctagrostis* and both species produce much more seed in disturbed than in undisturbed (natural) sites. Seedlings remain small the first year but grow rapidly the second, sending out rhizomes from which new shoots arise. Cold soils inhibit both shoot and root growth, but *Arctagrostis* is better adapted than is *Calamagrostis*, producing larger shoot systems and larger and deeper penetrating root systems.

Microenvironmental data show that in disturbed seismic lines in the tundra more snow accumulated and remained longer, the surface soils are $2^{\circ}$ to $3^{\circ}C$ warmer than in undisturbed hummocks, and the active layer is significantly deeper. These microenvironmental changes result in habitats more favourable for plant growth and, of the species available, *Arctagrostis* and *Calamagrostis* are the best colonizers. Because of this, both species should be included in any seed mixes used in the Low Arctic and northern Boreal Forest.

The revegetation studies had two major objectives; to continue an assessment of the field plots at Norman Wells, Inuvik, Tuktoyaktuk, and Prudhoe Bay, and to summarize the literature and unpublished data from the various studies conducted in Alaska and Canada in the past three years.

Of the species tested, Arctared and Boreal creeping red fescue and Nugget Kentucky bluegrass are the most successful in the northern Boreal Forest. To this are added the two native grasses discussed above; grasses that establish slowly but grow rapidly the second year. Within the northern Boreal Forest, added to the above species, are meadow foxtail, slender wheatgrass and Engmo timothy--good because of their early establishment, overwinter success and growth the second year. The legumes Aurora alsike clover and Falcata alfalfa were fairly successful on warmer soils from Inuvik south, and they have the potential of fixing nitrogen. Moist soil is essential for seedling establishment. This is best illustrated by the lack of plant cover on the warm gravel soil over the Inuvik hot oil loop and the best plant cover over the warm mineral soil over the Norman Wells hot gas loop. Seeding rates of 5 to 10 lb/ac resulted in a 30 to 50 per cent plant cover for the best species while rates of 30 to 50 lb/ac resulted in greater cover (in other studies). Seeding rates of 75 to 100 lb/ac would probably result in little increase in plant establishment and could result in less due to competition for moisture. Seeding is best done in spring or late fall unless there are summer rains. Rates of seeding by species for the Arctic as well as fertilizer levels are discussed. Most agronomic species produced seed the second year, especially at fertilized plots. This was less evident at Prudhoe Bay than at Tuktoyaktuk and south.

Introduced agronomic species will maintain themselves in disturbed sites, but seeding them into native tundra vegetation has not been successful. Reseeding does not prevent melt-out and possible subsidence but it will reduce soil erosion, except possibly on side slopes. Vegetation established by presently-known techniques does not appear to grow rapidly enough in the Arctic to restore soil energy budgets, at least within the first three years. However in the Boreal Forest this seems to be more feasible because of greater litter accumulation. Nutrient rich grasses are preferred food of both small and large mammals, and grazing plus the consumption of seed by birds may reduce the effectiveness of revegetation in some areas as it does in more temperate regions.

In the High Arctic of Devon Island (Truelove Lowland) the simulated grazing experiments indicate that clipping of plants in two successive years does little damage provided the roots remain intact. Spillage of Arctic diesel is as detrimental to plants as is crude oil in the Low Arctic. In both regions bacterial populations increase in these hydrocarbon contaminated soils. Fertilizer increases plant growth but may be of minor value in stimulating plant growth in the generally sparsely vegetated areas where surface disturbance is most likely.

While massive ice is less common in the islands, ice wedges do occur especially in gravelly or sandy raised beach ridges. Of greater importance are the ice-rich strata in fine textured soils that appear to trigger natural slumping on some slopes and provide wet spots on scraped runways in frost-boil dominated soils.

The development of an impact sensitivity map with text for the Fosheim Peninsula, Ellesmere Island, will aid regional planning of developmental operations. A similar map of the Queen Elizabeth Islands is planned.

# INTRODUCTION

The third and final year of this research was devoted to completing the program on: a) implications of topography and drainage on soil formation and on the status of soil and plant nutrients in the Low Arctic; b) the ecological characteristics of two native grass species that enable them to grow so well in surface-disturbed soils in the Low Arctic; c) the species and species mix, fertilizer levels and substrate conditions that appear most conducive to revegetation within the Low Arctic and northern Boreal Forest; and d) plant response to simulated grazing, diesel fuel spillage, and fertilizer addition, and the extent and implications of surface disturbance to the ice-rich strata that frequently underlie fine textured soils in the High Arctic. New one-year projects included the partition of solar energy with various kinds of surface disturbance at Norman Wells and on the Tuktoyaktuk Peninsula, and a map of impact susceptibility to land surfaces in the Fosheim Peninsula, Ellesmere Island, as a preliminary one for the Queen Elizabeth Islands.

# ENERGY BUDGET CHANGES FOLLOWING SURFACE DISTURBANCE TO TWO NORTHERN VEGETATION TYPES

by

Richard W. Haag

## INTRODUCTION

The environmental impact of petroleum exploration and related activity in the Canadian North has been well documented in recent years. The construction of winter access and supply roads and seismic lines has often resulted in a visible disturbance to or removal of vegetation; evidence now suggests that under many conditions natural revegetation occurs, and at a fairly rapid rate (Hernandez, 1972). Physical effects are often visible as well, particularly in areas of fine-textured soils with high ice content. If the upper permafrost melts, surface subsidence may lead to long-term environmental damage (Rempel, 1970; Bliss and Wein, 1972).

The cause of these physical effects lies in an alteration in the distribution of radiant energy resulting from a change in the intercepting surface. In an undisturbed situation, both long and short-wave radiation strike a heterogeneously vegetated surface. The albedo determines the proportions of each which are reflected and absorbed. The surface itself emits long-wave radiation at a rate proportional to its absolute temperature. The remaining absorbed net radiation is disposed of as soil heat flux, as latent heat, and as sensible heat. A relatively minor portion is converted to chemical energy through photosynthesis. This small gain in energy, however, is generally balanced by energy released during respiration.

Observations of natural and man-induced surface perturbations and limited experimental data indicate the importance of an insulating surface layer (normally peat in an undisturbed situation) in preventing permafrost degradation. Winter roads of compacted snow or snow-ice over intact peat have been used since 1969 (Bliss and Wein, 1972; Kerfoot, 1972) with little resultant surface degradation. Crude oil applied to the surface, while killing vegetation and lowering albedo, has not led to permafrost melt in various tundra sites (Bliss and Wein, 1972; Wein and Bliss, 1973). Tundra and forest-tundra fires have led to increased depth of the active layer but have seldom led to extensive meltout and surface subsidence except on slopes (Bliss and Wein, 1972).

The present study was undertaken to determine how the relationships between the components of energy dissipation in two northern vegetation types were altered by surface disturbance, and the effects of such alteration on the physical environment.

## STUDY AREAS

This work was carried out from May 31 to August 25, 1972, at Norman Wells and Tuktoyaktuk, N.W.T. The control study area at Norman Wells was located in spruce-larch forest, burned within the past 30 years; a 1971 seismic line provided the disturbed environment for intensive comparative study. Additional extensive measurements were made over controlled burn and oil-spill plots. Work at Tuktoyaktuk was carried out in upland dwarf shrub-heath tundra, with intensive comparative work done along a section of winter road in use since 1970. Extensive measurements were made on controlled burn and oil spill plots, and on revegetation plots seeded in 1970, 1971, and 1972.

## METHODS

Continuous records were kept of total radiation (Belfort Actinograph), air temperature and humidity (Belfort Hygrothermograph), wind velocity (Belfort totalizing Anemometer) and precipitation (Tri-chek gauge) at both control sites. Permafrost depth was determined with a 1 cm. probe and soil moisture gravimetrically biweekly at both sites.

Total incoming solar radiation was measured with Kipp solarimeters at 0, 0.5 and 1.0 m above the ground surface. Reflected short wave (albedo) was measured with a Kipp albedometer at a height of 0.5 m, and net radiation with Schenck and Thornethwaite net radiometers at 0.5 and 1.0 m. Soil heat flux was measured at 0 and 5 cm. depth with Middleton CSIRO-type heat flux transducers. These parameters were recorded sequentially for 1 min. each with an Esterline Angus potentiometric recorder. Frequency of measurement was 10 min.

Vapor pressure and air temperature were measured with an Atkins aspirated psychrometer, and wind velocity with a Hastings omnidirectional hot wire anemometer at 6 hr. intervals at 5, 25, and 50 cm. height. Soil temperatures were measured at 6 hr. intervals at 5, 10, 15, 20, 30, 50, 70 and 100 cm. depth with 28 AWG copper-constantan thermocouples and a Wescor potentiometer. Air (5, 25 cm.) and surface temperatures were recorded hourly with Grant temperature recorders and shielded thermistor probes.

Measurements of albedo and net radiation as a per cent of total incoming were made over burned, oil spill, and reseeding plots, to provide some measure of the effect of these manipulations on energy exchange.

The following symbols and sign conventions are followed in this report:

I - short-wave incoming solar radiation

Rr - short-wave reflected (albedo)

$E6T^4$ - Stefan - Botlzmann black body radiation

T - temperature in $K^o$

Rs - net short-wave incoming (I-Rr)

Rn - net radiation

S - sensible heat exchange

LE - latent heat of vaporisation, condensation, sublimation, fusion

G - soil heat flux

Radiant energy fluxes toward the ground surface, a 2-dimensional plane, are taken as positive. Fluxes away from this surface in either direction are negative. Thus, soil heat flux during the day (downward, heating the soil mass) has a negative sign, for example.

## RESULTS AND DISCUSSION

### Tundra

#### Albedo and Long-Wave Radiation

Removal of vegetation and surface peat on the winter road in the tundra resulted in a lowering of albedo from approximately 15 per cent in the control to 10 per cent. The decrease in albedo brought about an increase in net radiation of 18 per cent in the winter road for the entire season (Table 1). On the burn and oil spill plots, albedo decreased to 10 per cent and 7 per cent respectively.

#### Latent Heat Loss

With a plentiful supply of water available on the surface, evaporation from the winter road exceeded control values (Table 1) during the early part of the season. As the soil surface dried, however, the resistance to water loss from the surface increased, LE/Rn in the winter road decreased (Fig. 1), and control latent heat loss exceeded

Table 1. Monthly and total radiation flux values- tundra control and winter road, Tuktoyaktuk, N.W.T.( gcal $cm^{-2}$ )

| Date | Control Rn | Control LE | Control G | I | Winter Road Rn | Winter Road LE | Winter Road G |
|---|---|---|---|---|---|---|---|
| 1-8 June | 1486.4 | 743.2 | 184.0 | 3616.8 | 898.6 | 691.9 | 46.4 |
| 9-24 June | 5230.4 | 2124.4 | 1036.8 | 11566.4 | 5276.8 | 2216.3 | 1220.8 |
| 25-30 June | 1296.0 | 570.2 | 195.4 | 2289.6 | 1382.4 | 470.0 | 290.3 |
| June | 8012.8 | 3437.8 | 1416.2 | 17472.8 | 7557.8 | 3378.2 | 1557.5 |
| 1-2 July | 518.4 | 243.6 | 72.6 | 979.2 | 555.8 | 194.5 | 94.5 |
| 3-7 July | 1332.0 | 652.7 | 186.5 | 2664.0 | 1404.0 | 561.6 | 266.8 |
| 8-13 July | 1425.6 | 727.1 | 199.6 | 3110.4 | 1512.0 | 695.5 | 302.4 |
| 14-21 July | 1555.2 | 902.0 | 326.6 | 3225.6 | 1612.8 | 693.1 | 403.0 |
| 22-29 July | 1267.2 | 823.6 | 354.8 | 2534.4 | 1324.8 | 529.6 | 397.2 |
| 30-31 July | 417.6 | 300.7 | 87.7 | 835.2 | 432.0 | 229.0 | 108.0 |
| July | 6516.0 | 3649.7 | 1227.8 | 13348.8 | 6841.4 | 2903.3 | 1571.8 |
| 1-5 August | 1044.0 | 751.7 | 219.2 | 2088.0 | 1080.0 | 572.4 | 270.0 |
| 6-11 August | 907.2 | 653.2 | 163.3 | 2073.6 | 1080.0 | 604.8 | 259.2 |
| 12-16 August | 324.0 | 217.1 | 61.6 | 684.0 | 410.5 | 221.7 | 106.7 |
| 17-22 August | 612.0 | 373.3 | 128.5 | 1332.0 | 763.0 | 396.8 | 213.6 |
| August | 2887.2 | 1995.3 | 572.0 | 6177.6 | 3333.5 | 1795.7 | 849.5 |
| Total | 17416.0 | 9082.8 | 3216.0 | 36999.2 | 17732.7 | 8077.2 | 3978.8 |

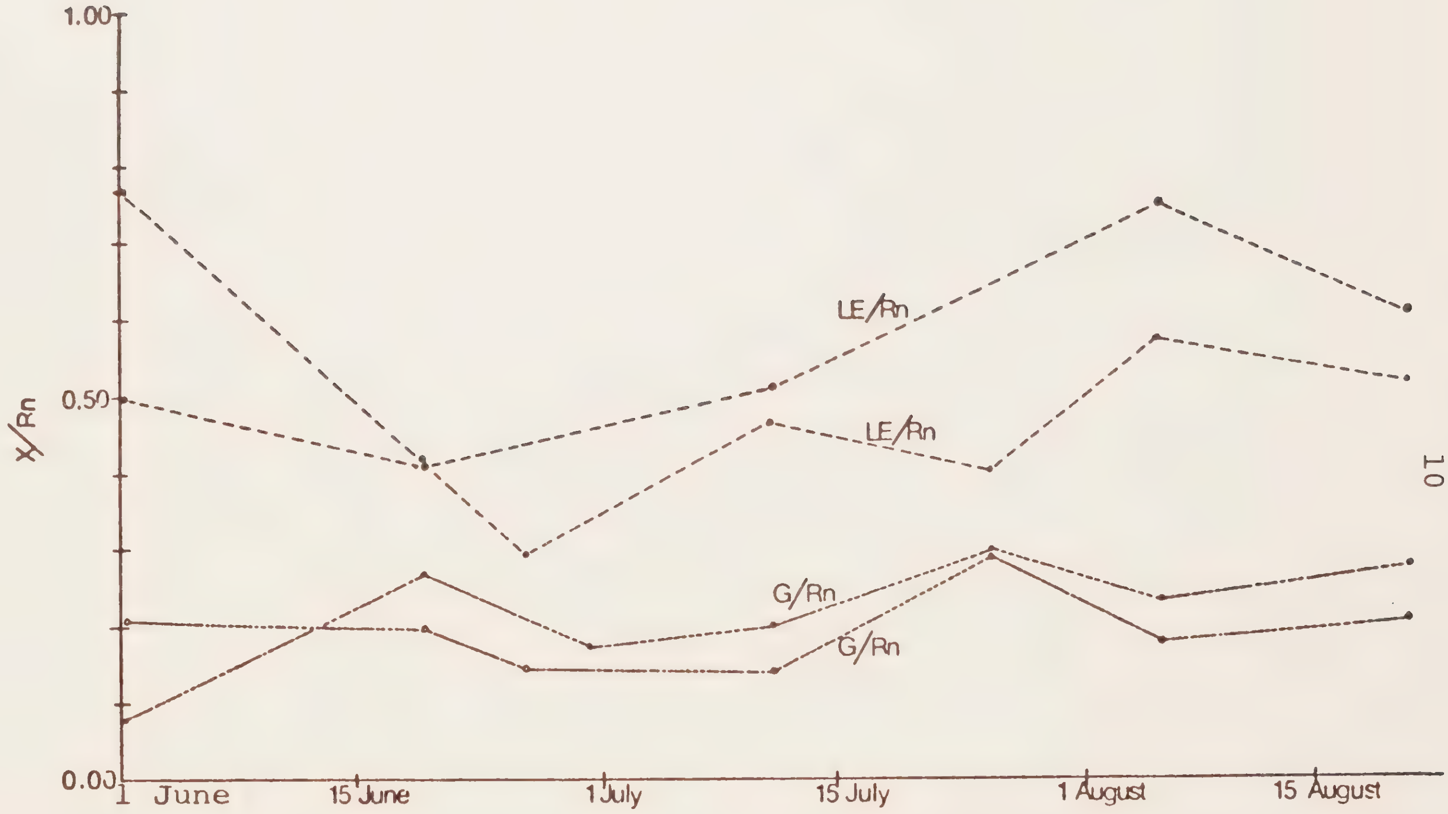


Fig. 1. Variation in latent heat loss and soil heat flux as percent net radiation for tundra control (open dots) and winter road surfaces (closed dots) during 1972.

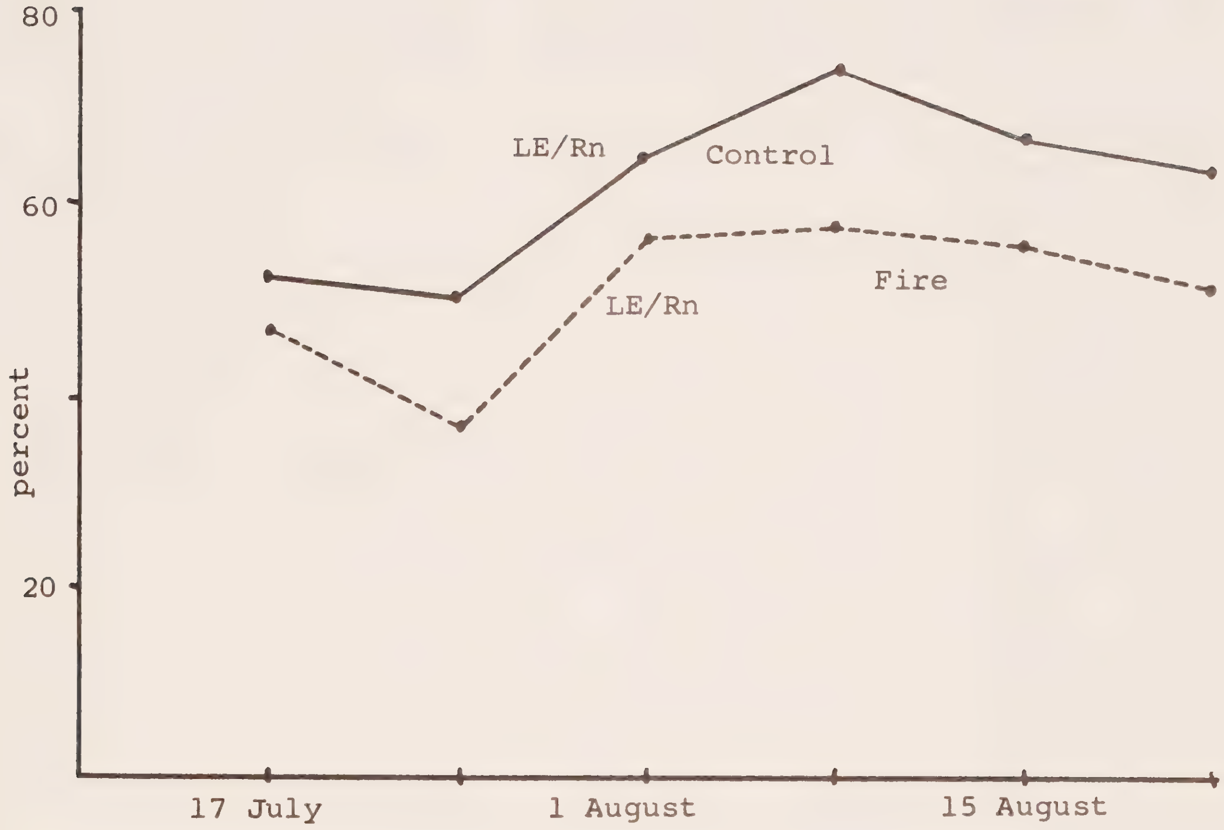


Fig. 2. Seasonal variation in latent heat loss following a tundra fire. LE- latent heat loss; Rn- net radiation.

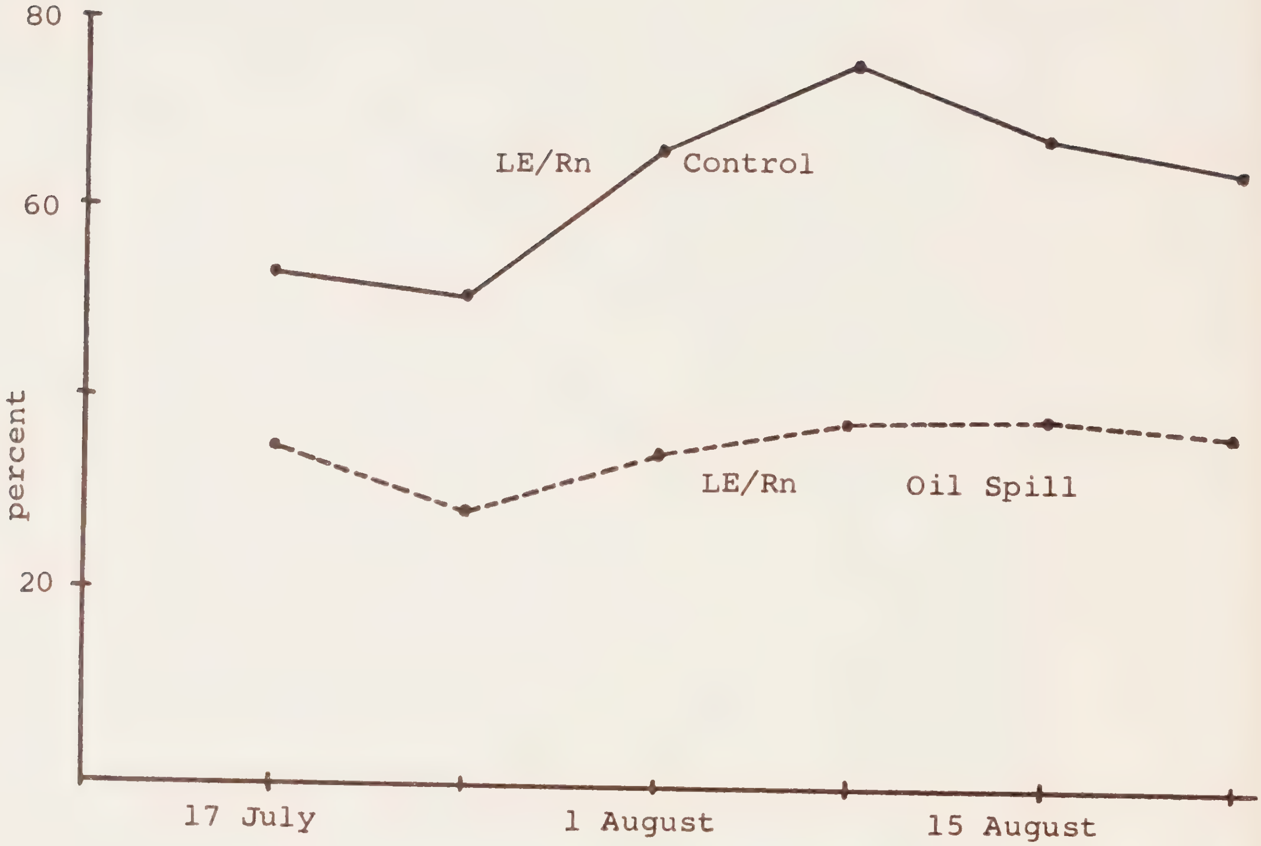


Fig. 3. Seasonal variation in latent heat loss following a tundra oil spill. LE-latent heat loss; Rn- net radiation.

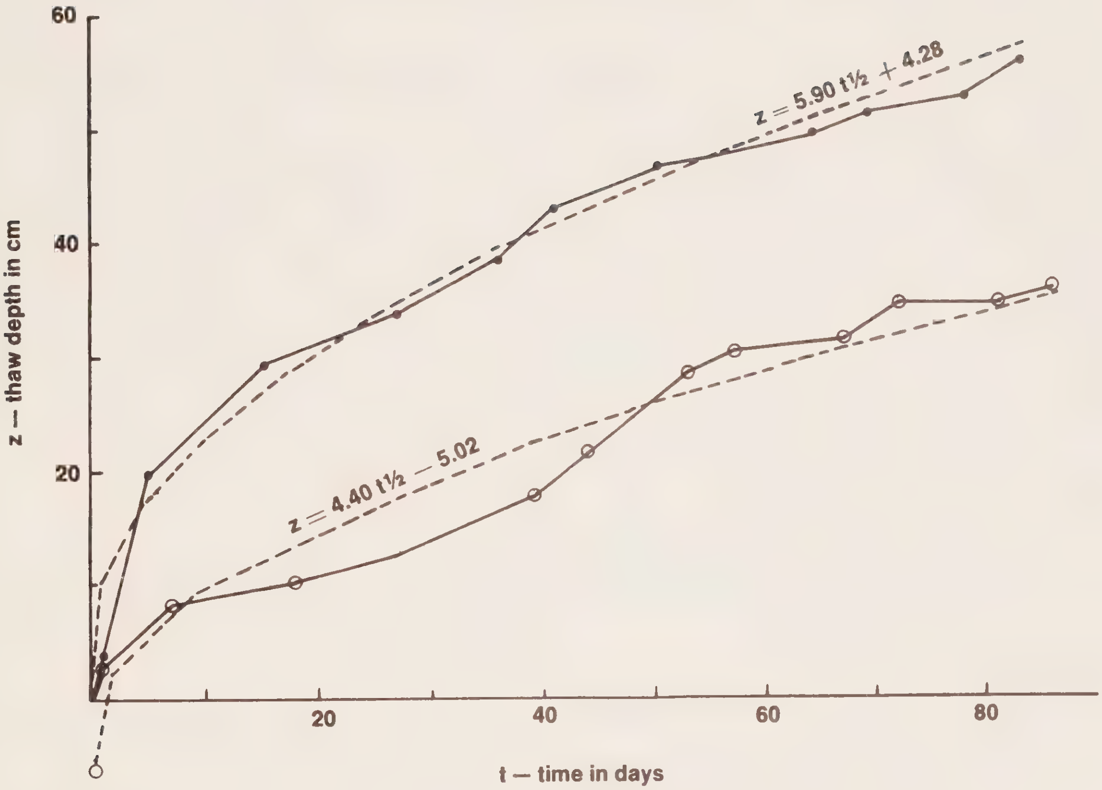


Fig. 3A. Depth of thaw plotted against time for tundra control (open dots) and winter road (closed dots). Time zero is 31 May in the control, and 2 June on the winter road. The dashed line is the plot against time derived from the linear regression of thaw depth on the square root of time.

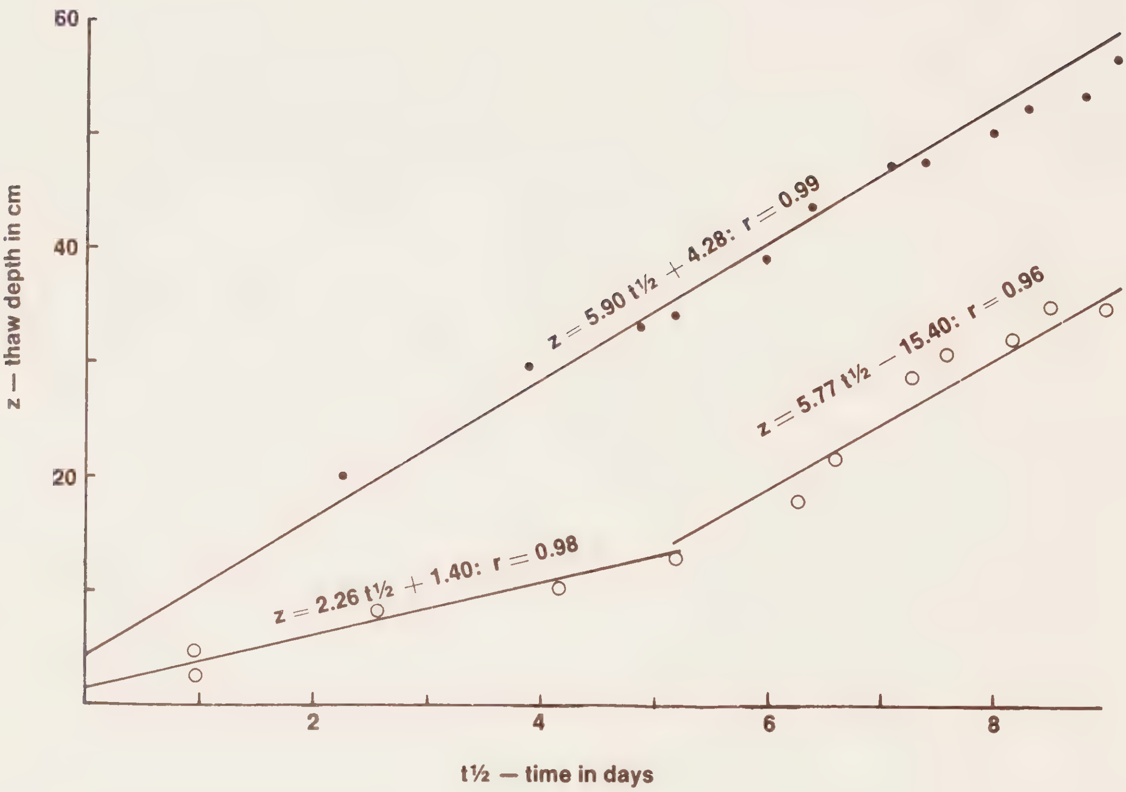


Fig. 3B. Depth of thaw plotted againt the square root of time for tundra control (open dots) and winter road (closed dots). The lines shown are derived by the method of least squares.

values on the disturbed site for the remainder of the season (Table 1). In both the burn and oil spill plots, damage to the vegetation likewise resulted in a lowering of latent heat loss, more pronounced in the case of the oil spill (Figures 2 and 3). With vegetation removed, and thus no access to subsurface soil moisture through a rooting mass, evaporation is more dependent on the moisture content of the soil surface layers. Where this is low, latent heat loss is low.

## Soil Heat Flux, Thermal Regime

A negative correlation was found between latent heat loss and soil heat flux in all disturbances. Resistance to upward heat loss increased as the soil surface dried and a greater proportion of absorbed net radiation went into soil heat flux, and G/Rn increased slightly (Fig. 1). As a result, the soil warmed faster and showed higher mean temperatures in the winter road from June to August. This was most pronounced where surface peat had been removed (Fig. 2). However, as peat thawed in the control, its thermal conductivity increased, and soil temperatures rose more rapidly than in the winter road.

In the burn and oil spill plots, soil temperatures were higher, but the fact that surface peat remained virtually intact prevented as large a temperature rise as in the winter road.

## Active Layer Depth

All disturbed surfaces had an increased soil thaw depth relative to the control. The organic surface layer of the soil was extremely critical to soil thaw depth. In the winter road, where this layer was absent, soil thaw proceeded at a nearly constant rate throughout the summer (Fig. 3B), when plotted against the square root of time (Drew *et al*; 1958). In the control, however, soil thaw was initially slow until the surface peat thawed, following which mineral soil thawed at a rate nearly identical to that of the winter road mineral soil (Fig. 3B). Total thaw depth in the winter road exceeded that of the control by 20 cm. at the end of the season. The principal function of the peat layer in regulating thaw depth seemed to be in delaying the onset of thaw in mineral soil due to the high ice content of the peat which must be melted (Kelley and Weaver, 1969).

A secondary effect was seen in the low thermal conductivity of peat acting as an insulator. The tundra burn was carried out after the peat thawed on July 10. Total thaw depth at the end of the season exceeded that of the control by 10 cm., indicating that the insulating effect after burning was insufficient to maintain an active layer depth comparable to that of the control plot.

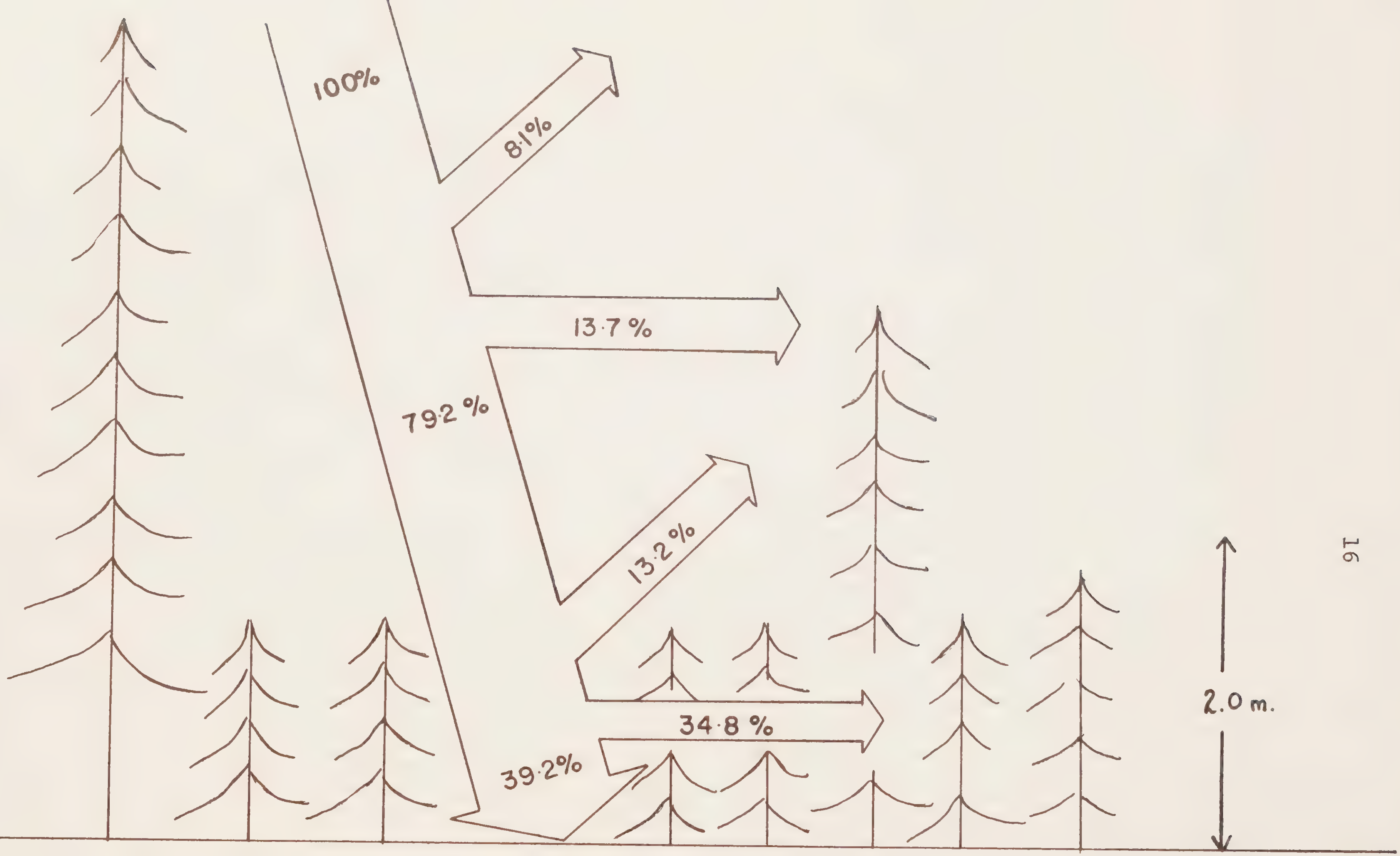


Fig. 4. Penetration of short wave (>3.2u) solar radiation in the boreal forest control site, Norman Wells, N.W.T. All percentages are percent of total short wave incoming radiation.

## Boreal Forest

The situation in the boreal forest at Norman Wells, with a well-stratified forest canopy, was somewhat more complex than in the tundra.

## Albedo and Net Radiation

Construction of a winter seismic line through the forest resulted in the removal of the tree and herb/low shrub strata, but left the moss layer intact. With the upper layers of vegetation removed, albedo of the seismic line actually increased to 13.3 per cent, against an average albedo of 13.1 per cent in the control boreal forest.

On the seismic line, all of the incoming radiation struck the ground surface during high to moderate sun angles. At low angles the adjacent forest provided some shading.

In the control, 79.2 per cent of total radiation penetrated to a height of 1 m, the average height of young spruce and larch in this old burn. Albedo accounted for 10.1 per cent of this energy (8 per cent of total incoming), leaving approximately 70 per cent of total incoming to penetrate to the surface. Slightly less than 50 per cent of this energy was absorbed by the vegetation, and was reradiated, used to evaporate water, or lost as sensible heat. Of the remaining energy 7.3 per cent (5.2 per cent of total incoming) was reflected by the lower vegetation and ground surface, leaving only 39.2 per cent of total incoming to penetrate to the ground (Fig. 4). Thus, although there was a slight increase in total-short wave reflectance on the seismic line, penetration of radiant energy to the ground surface increased greatly as the absorption of energy by the stratified canopy was lost.

Air and surface temperatures are higher within the forest at night, since the plant canopy reduced long-wave radiation loss. During periods of high sun angle coupled with low wind velocity, control air and surface temperatures may exceed values on the winter road. Generally, however, these temperatures were lower during the day in the forest, although air temperature showed a slower decrease with height during the day in the forest, as wind velocities were reduced within 1 m of the ground surface.

## Latent Heat Loss

Latent heat loss from the ground surface, based on lysimeter data, was lower in the forest throughout the season as wind velocities were reduced within the vegetation. Evapotranspiration from the ground surface in the control was approximately 70 per cent of that from the ground surface on the seismic line, or 35 per cent of net radiation against 50 per cent on the seismic line.

However, approximately 35 per cent of total incoming radiation was absorbed within the tree/shrub strata in the control. Of this, 30 per cent (20 per cent of net radiation) was used to evaporate water, resulting in a total LE/Rn ratio of 0.55 in the control, against 0.50 in the seismic line.

### Soil Heat Flux

Soil heat flux in the seismic line averaged approximately 17 per cent of incoming radiation, or almost 30 per cent of net radiation. The major factor contributing to this increase was the removal of the shading effect of vegetation. Only 39.2 per cent of total incoming radiation penetrated to the ground (Fig. 4), and only 20 per cent of this fraction (8 per cent of total incoming) went into soil heat flux. Vegetation in this respect played a more important role in the boreal forest than in the tundra.

The increase in soil heat flux resulted in higher soil temperatures throughout the season in the seismic line. Thaw proceeded at a nearly constant rate in both soils when plotted against the root of time (Fig. 5B); the organic layer of approximately 30-40 cm. prevented the changing thaw rate seen in the tundra from occurring, since soil thaw was almost entirely confined to peat.

Thaw rate in the seismic line exceeded that in the control by 68 per cent (Fig. 5B), and total thaw depth exceeded control values by 17 cm. at the end of the season (Fig. 5A). Thaw depths were less than in the tundra, due to the increased thickness of the peat layer, coupled with the shading effect of undisturbed vegetation.

## CONCLUSIONS

The effects of disturbance to vegetation and the soil surface showed major quantitative differences between tundra and boreal forest.

### Tundra

Surface disturbance in the tundra resulted in an albedo decrease and an increase in net radiation in all cases. Partitioning of net radiation changed following disturbance (Fig. 6).

Latent heat loss showed the greatest decrease on the oil spill, where oil on the surface impeded water vapor diffusion. Where peat and vegetation were removed on the winter road, latent heat loss showed a major decrease. The smallest decrease was seen on the burn, where vegetation was removed, but peat remained essentially intact.

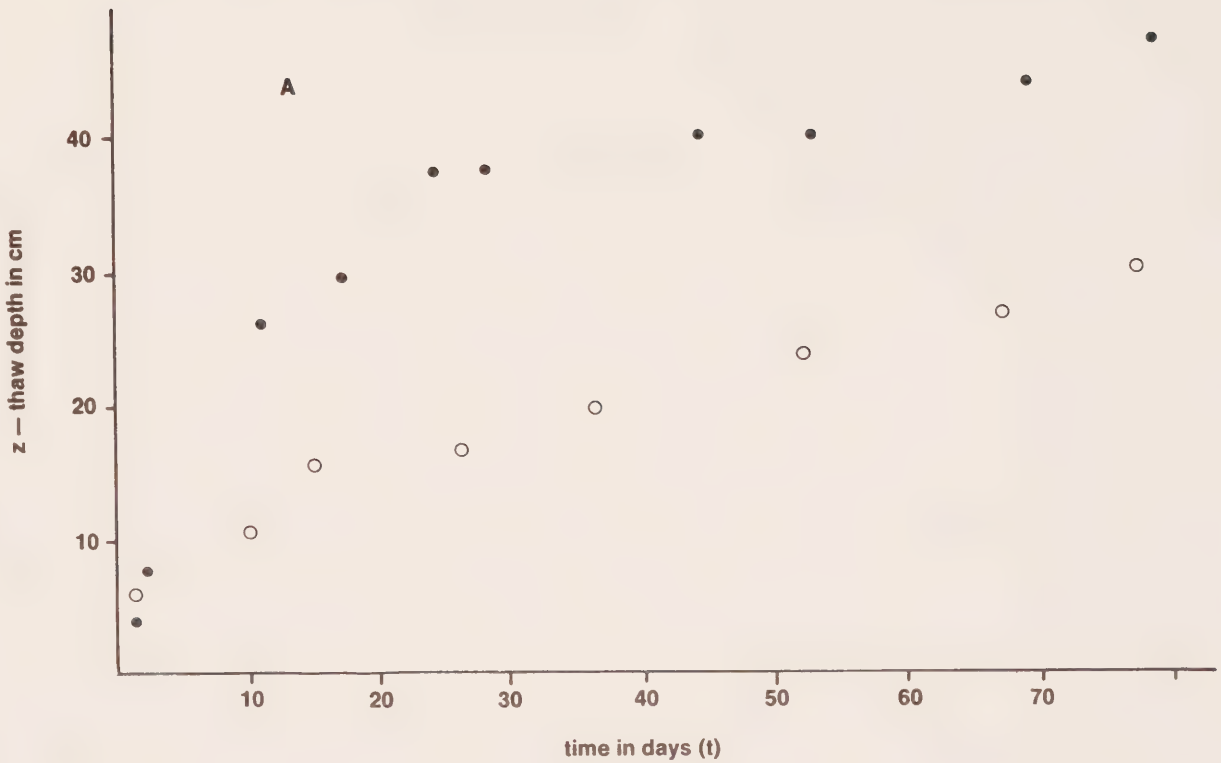


Fig. 5A Thaw depth (z) vs. time (t) in boreal forest control and seismic line. Open circles refer to control, closed dots to seismic line. $t_0$ in the control 27 May, and in the seismic line, 25 May.

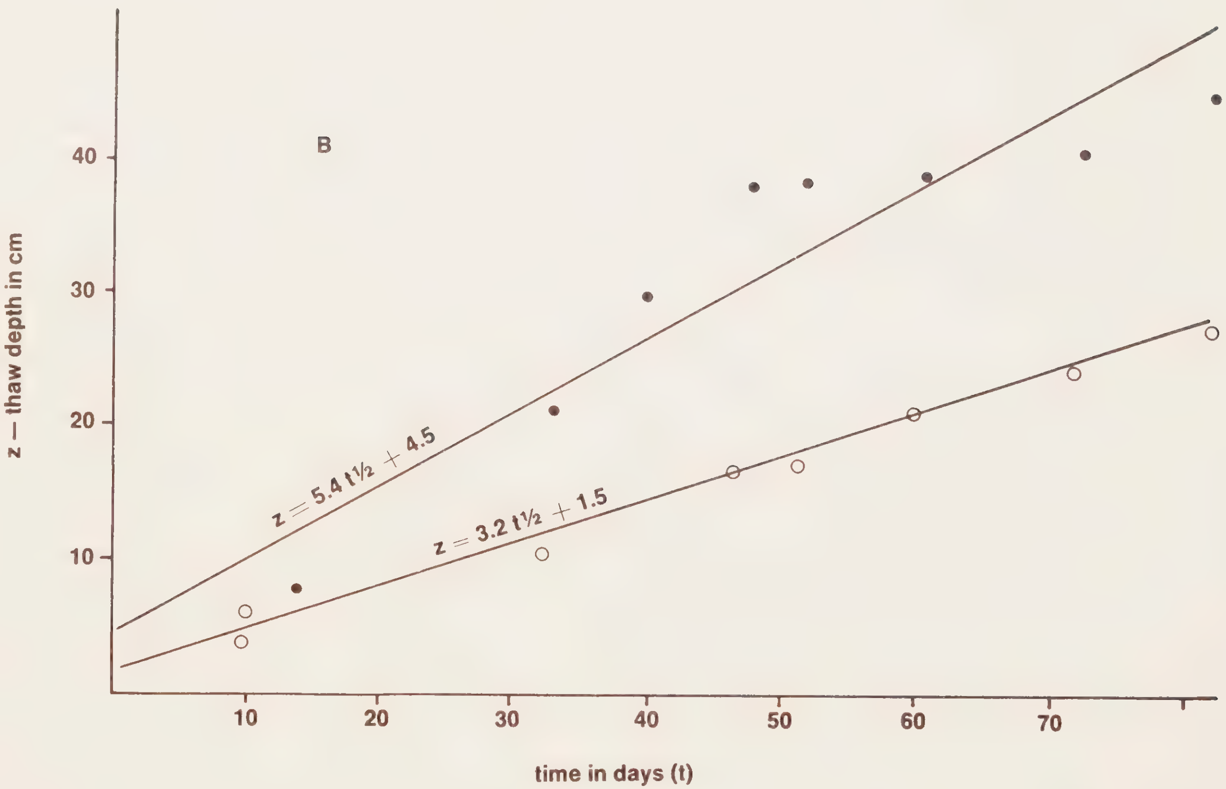


Fig. 5B. Thaw depth (z) vs the square root of time ($t^{\frac{1}{2}}$) in boreal forest control and seismic line. Open circles refer to control, closed dots to the seismic line. Straight lines shown are derived from Least Squares Method, and both have r=0.98$^{8*}$, highly significant (p=0.01).

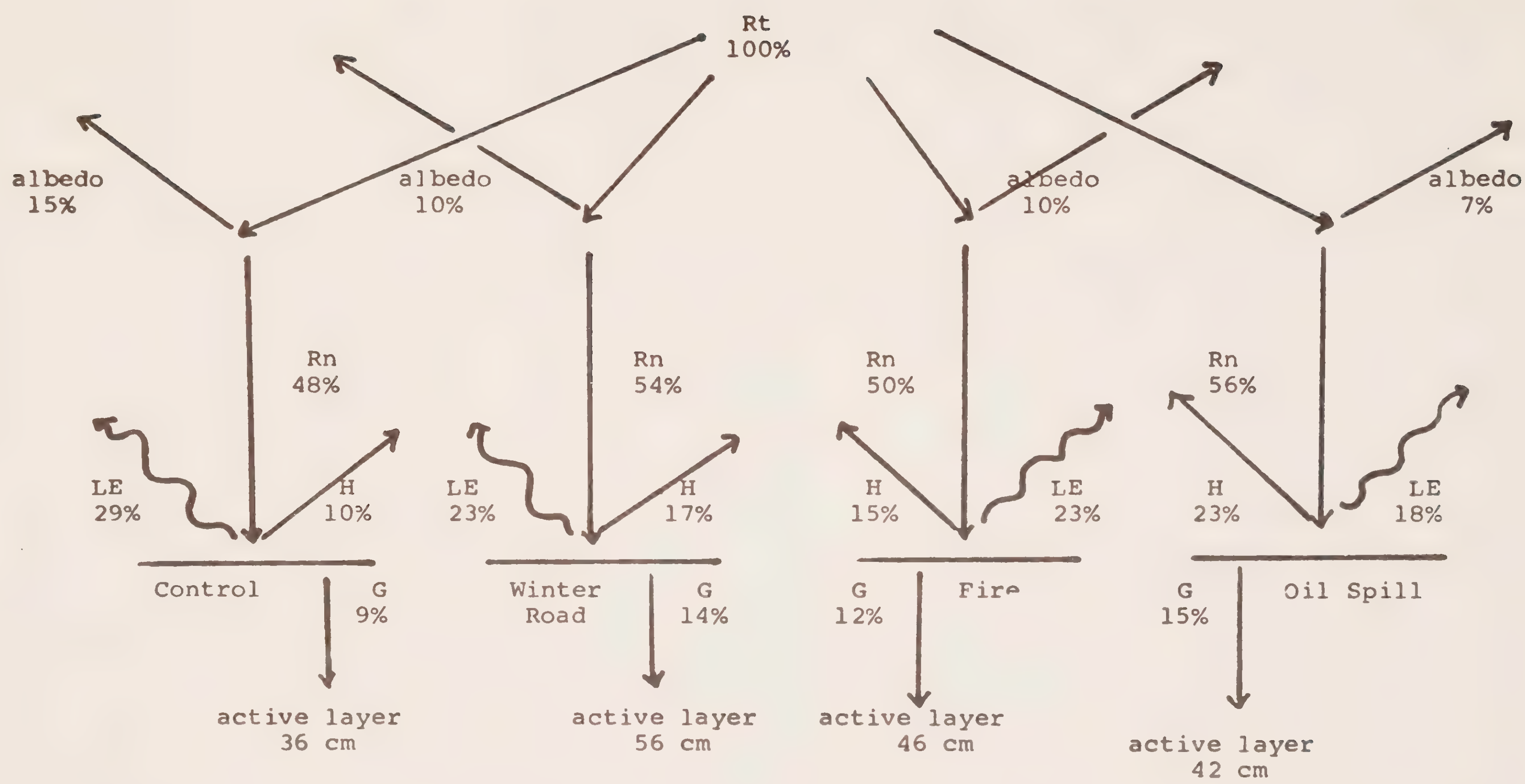


Fig. 6 Schematic diagram showing the effect of surface disturbance on partitioning of radiant energy flux in upland tundra. Values are for a typical clear midsummer day, and are expressed as percent of total incoming (Rt). Rn- net radiation, LE-latent heat flux, G- soil heat flux, H- sensible heat flux.

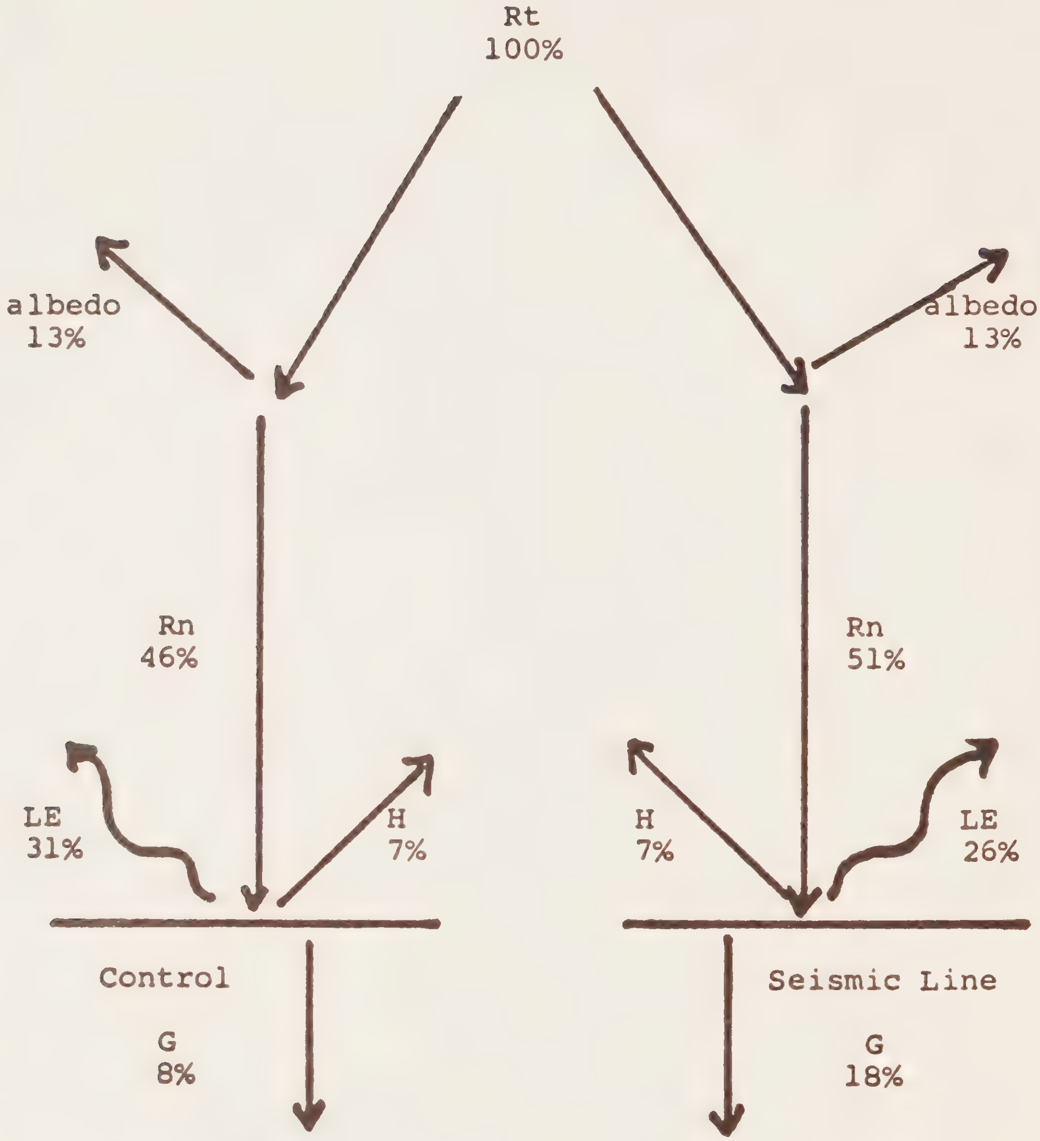


Fig. 7 Schematic diagram showing the effect of vegetation removal on the radiant energy budget of boreal forest. Rt-solar incoming: Rn-net radiation; LE-latent heat flux; H-sensible heat flux; G-soil heat flux.

Vegetation provided an access to subsurface moisture through its roots, allowing dissipation of a large fraction of net radiation as latent heat. Intact peat provided a large surface area for evaporation but lacked the access to a deep water supply.

Latent heat loss and soil heat flux in the tundra were inversely related; if heat could not be dissipated upward, it was transported downward. The magnitude of increase in soil heat flux and its effects were dependent on the extent of surface disturbance. Where peat was intact, the increase in soil heat flux resulted in a small increase in ground temperatures. The high water content of peat, however, prevented degradation of permafrost, as in the case of the surface fire.

Where peat was removed, mineral soil with a high thermal conductivity and low water content was exposed, resulting in rapidly increasing soil temperatures, and an increased active layer depth which lead to surface subsidence (Fig. 6).

## Boreal Forest

The increased height and complexity of vegetation in the boreal forest rendered the area more susceptible than tundra to vegetation disturbance. Although removal of vegetation resulted in little change in albedo or net radiation from an overall point of view, there was a major change with respect to the ground surface; approximately 60 per cent of total radiation was normally reflected, or absorbed and dissipated before reaching the ground surface in an undisturbed situation. Vegetation removal resulted in a large increase in energy penetration to the ground surface.

Total latent heat loss showed only a slight (10 per cent) increase following vegetation removal, since wind velocity reduction within the control canopy normally reduced water vapor loss from the surface.

However, increased light penetration resulted in a 30 per cent increase in soil heat flux. A thick peat layer with high water content remaining on both disturbed and undisturbed surfaces prevented this increase in soil heat flux from producing a major change, either in the soil thermal regime or in active layer depth, due to the high specific heat and low thermal conductivity of this layer. In contrast, a major change in the soil thermal regime and active layer depth was seen on the tundra winter road, where the peat layer was removed. However, in areas with thinner peats, such an increase in soil heat flux as a result of vegetation removal could result in large increases in active layer depth, and possible surface subsidence.

## IMPLICATIONS AND RECOMMENDATIONS

It is first of all assumed that any form of construction (access roads, drill pad, pipeline) will necessarily result in disturbance to or removal of vegetation.

Tundra vegetation exerts little functional effect on the energy budget, which, following disturbance, might lead to long term environmental damage. Although vegetation type may be a valuable indicator in defining other environmental characteristics, removal of tundra vegetation alone does not create major problems.

In the boreal forest, the potential for long term environmental damage increases with the complexity of the vegetation, for in mature, complex communities, active layer depth will exist in equilibrium with short wave penetration through the canopy. The least change in the energy budget will occur with disturbance to the least stratified canopy. Direct consideration, therefore, should be given to vegetation type in planning construction in these areas.

Peat thickness and the characteristics of the soil itself are critical to active layer depth. Any measures which can be taken to insure that the peat surface remains intact (regulation of total passage or weight to be hauled on snow/ice roads) are advisable. Where disturbance to peat is unavoidable, consideration should be given to replacement of this material, or to substitution of commercial peat or some other insulating material to prevent a large increase in active layer depth and provide a bed for restoration of vegetation.

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# TOPOGRAPHIC INFLUENCE ON SOIL AND PLANT NUTRIENTS

by

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## INTRODUCTION

Topographic position is possibly the most important physical factor influencing biological community patterns. In the Arctic its influences are somewhat masked by the presence of permafrost, which impedes internal drainage regardless of topographic position. As a result, the water table fluctuates seasonally with the active layer, which seldom exceeds a depth of 60 cm by late August in the Mackenzie Delta upland regions.

The upland tundra landscape east of the Mackenzie Delta is gently rolling with a maximum relief of 100 m (Mackay, 1971; Rampton, 1971) and diverse habitats have developed in close proximity to each other.

This study was carried out to evaluate differences in physical and chemical characteristics of vegetation-soil components among several topographic positions in the upland tundra east of the Mackenzie Delta (mapped in the 1971-72 A.L.U.R. report). A better understanding of the interactions of physical and biological factors will aid in the maintenance of these natural habitats. Also, with increasing development of resources, such an understanding should aid in reconstruction and rehabilitation of man-induced disturbances.

## STUDY AREAS

Thirty to fifty per cent of the region is covered by lakes (Mackay, 1963), most of which have a thermokarst origin, or have had their original configurations greatly modified by thermokarst process. The topography of this plain varies from one of closely spaced steep hills to one of broad, low, gently sloping hills. Depressions separating the hills may be more than 2 km across (Rampton, 1971).

Glacial deposits, probably not all from the Laurentide ice sheet, cap Pleistocene sand deposits over most of the area (Rampton, 1971). During the last glaciation, the northward moving ice sheet was separated into two tongues by the Caribou Hills, one tongue extending northwest along the trough of the Delta, and the other northeast along the north end of Eskimo Lakes (Fyles, 1967).

The study area near Tuytoyaktuk has 0.7 to 2.5 m of interbedded sands and gravels (Bouchard and Rampton, 1967). Soils are coarse-textured, mostly sandy loams. Vaccinium vitis-idaea spp. minus, Eriophorum vaginatum spp. vaginatum, Ledum palustre spp. decumbens and Betula nana spp. exilis are the dominant vascular species in depressions. Empetrum nigrum spp. hermaphroditum, Vaccinium vitis-idaea spp. minus, Betula nana and Salix glauca spp. acutifolia dominate mid-slope and hilltop positions.

Glaciofluvial sands and gravels, possibly up to 10 m thick,were left by a former glaciation and cover most of the Tununuk Point area. In places, they are capped by till (Rampton, 1971). Soils are slightly coarser-textured than at Tuktoyaktuk but topographic relief is similar and slopes are 9 to 15 per cent. In order of importance in depressions are Vaccinium uliginosum spp. alpinum, Arctostaphylos rubra, Dryas integrifolia spp. integrifolia and Carex spp. Vaccinium uliginosum, Dryas integrifolia and Arctostaphylos rubra are dominant in midslope and hilltop positions.

The study area in the Caribou Hills consists of gravels and sands deeply pitted by thermokarst depressions. Drained lakes which occupied these depressions are common (Rampton, 1971). The oriented lakes in the Caribou Hills are a series of meltwater channels (Mackay, 1963). Broad hills and more gentle slopes are characteristic of this area. Slopes average 4 to 12 per cent and relief is 30 to 40 m. Soils are finer textured than at Tuktoyaktuk and Tununuk Point, as is shown by more frost boil activity. Vaccinium uliginosum is present in all topographic positions. Other important species include Vaccinium vitis-idaea and Betula nana in most topographic positions, while Eriophorum vaginatum occupies bottom positions only. Ledum palustre is fairly common in midslope and hilltop positions and occasionally inhabits bottom positions.

## METHODS

Sampling areas were selected near Tuktoyaktuk, Tununuk Point, and Reindeer Station. At each location, three areas were chosen from air photos and ground reconnaissance, each of which had a sequence of hilltop, midslope, and cottongrass-heath bottomland. Each of these is referred to as a stand.

A 30 m baseline was laid out in each stand, and three random points were located along the line where 0.25 $m^2$ quadrats were placed. Plant cover was estimated and clipped within each quadrat. The clipped material was separated into standing live, dead, and litter. Mosses and lichens were

clipped to 2 cm below the surface. After clipping, a small soil pit was dug down to the permafrost table under each quadrat and the profile described. Composite soil samples were then taken from all important horizons. Active layer depth measurements were made at one metre intervals along the 30 m baseline.

Soil and vegetation samples were frozen and shipped to Edmonton to be dried. Plant material was dried at 80° C, then weighed; soils were air dried. Plant material was ground to pass through 60 mesh, and sent to Alberta Department of Agriculture Soil and Feed Testing Laboratory in Edmonton for analyses of nitrogen, phosphorus, calcium and potassium. Soil samples were evaluated for colour (Oyama and Takehara, 1967) then ground to pass 2 mm. Part of each sample was sent to the Alberta Department of Agriculture Soil and Feed Testing Laboratory for analyses of available and total nitrogen, available phosphorus and potassium. The rest of the sample was analyzed for texture (Bouyoucos, 1951), loss on ignition, pH, exchangeable cations, total exchange capacity, and moisture retention at one-third and fifteen bars, according to the manual of Soil Laboratory Analysis prepared by the Alberta Soil Survey and the Department of Soil Science at the University of Alberta.

## RESULTS

### Physical and Chemical Soil Characteristics

Table 1 shows that field moisture increases in the surface layer from hilltop to depression. Differences between the two upper positions and the bottom position are significant. The mineral segment of the active layer does not show this trend as clearly as the surface horizon.

The organic layer increases in thickness downslope while the active layer decreases. This correlation is thought to be due to moisture and temperature interactions. Differences in active layer depths between the two upper positions and the lower position are also significant.

Organic matter, as indicated by loss on ignition, seems to determine the water retentive capacity at both 1/3 and 15 bar tensions. Soils high in organic matter are also less dense than hilltop soils.

Available water, as measured by the difference between water retained at 1/3 and at 15 bar tensions, is quite similar in all topographic positions and organic materials. Available water in organic material is not different from available water in mineral material measured at the same position on the transect.

Table 1. Physical and Chemical characteristics of the surface organic layer for three topographic positions at Tuktoyaktuk, Tununuk Point and Reindeer Station. +

| Soil Characteristics | Hilltop | Midslope | Depression |
|---|---|---|---|
| Organic Layer Thickness (cm) | 10.0 ± 2.5 | 9.3 ± 2.2 | 15 ± 3 |
| Active Layer Depth (cm) | 40 ± 2.7 ** | 41 ± 2.8 | 30 ± 2.4 |
| Field Moisture (%) | 157 ± 13 *** | 165 ± 7 | 282 ± 15 |
| 1/3 Bar Water Retention (%) | 99 ± 4 *** | 113 ± 7 | 123 ± 6 |
| 15 Bar Water Retention (%) | 88 ± 5 ** | 99 ± 4 | 113 ± 7 |
| Loss on Ignition (%) | 57 ± 3 *** | 64 ± 3 | 71 ± 4 |
| Density of 2 mm fraction (g/cc) | 0.37± 0.022** | 0.35± 0.026 | 0.29± 0.014 |
| pH | 5.5 ± 0.27* | 5.5 ± 0.23 | 5.0 ± 0.2 |
| Total Nitrogen (%) | 1.4 ± 0.07 | 1.55± 0.07 | 1.5 ± 0.1 |
| Available Nitrogen (ppm) | 0.5 | 0.5 | 0.5 |
| Available Phosphorus (ppm) | 4.6 ± 1.0 ** | 2.6 ± 0.6 | 1.9 ± 0.5 |
| Available Potassium (ppm) | 169 ± 20 *** | 130 ± 17 | 90 ± 19 |

\+ means and their standard errors represent 9 samples

* Difference between hilltop and depression is significant at the 90% confidence level

** Difference between hilltop and depression is significant at the 95% confidence level

*** Difference between hilltop and depression is significant at the 99% confidence level

High densities of organic material are associated with more humified conditions (Table 1). Depressions contain organic material completely fibric in nature, whereas hilltops and midslopes commonly have surface fibric layers of several centimetres underlain by mesic and humic layers.

Soil pH values are lowest in depressions, and are similar on midslopes and hilltops (Table 1). Average pH values are 5.0, 6.5, and 5.5 for Tuktoyaktuk, Tununuk Point and Reindeer Station respectively.

Available soil nutrients are low. Available nitrogen is often absent and when present, occurs in minor amounts. Total nitrogen of the organic layer is higher than that in plant tissue and litter material but there is no difference in total nitrogen among positions and organic matter types. Total nitrogen reserves are greater in depressions than the other two positions because of greater amounts of organic material in depressions. Organic compounds containing nitrogen are continually added to the organic layer by plant tissue but greater percentages are recycled on hilltop and midslope positions than in depressions so that net reserve nitrogen gains are probably greater in bottom positions. Available phosphorus and potassium decrease with a decrease in topographic position.

## Standing Crop

Standing crop is similar among topographic positions but litter is significantly lower in bottom positions (Table 2). Standing crop includes cryptogam, and live and dead attached vascular material. Bottom positions have high amounts of attached dead, mostly *Eriophorum vaginatum*.

Leaf, stem and litter standing crop are greatest on midslope and hilltop positions and least in bottom positions, whereas the cryptogam portion of the total biomass increases from hilltop to depression positions (Table 3).

Table 3. Percentage composition of biomass components at Tununuk Point (n - 9)

| Component | Hilltop | Midslope | Depression |
|---|---|---|---|
| Leaf | 8 | 8 | 5 |
| Live and Dead Stem | 11 | 12 | 7 |
| Cryptogam | 27 | 34 | 62 |
| Litter | 54 | 46 | 26 |

Table 2. Biomass and chemical composition of standing crop and litter for three topographic positions at Tuktoyaktuk, Tununuk Point and Reindeer Station. +

| Material | | Hilltop | Midslope | Depression |
|---|---|---|---|---|
| Standing Crop Material | Biomass ($g/m^2$) | 1000 ± 57 | 1000 ± 61 | 1100 ± 56 |
| | Nitrogen (%) | 1.1 ± 0.053 ** | 0.99 ± 0.022 | 0.84 ± 0.031 |
| | Phosphorus (%) | 0.104 ± 0.003 ** | 0.094 ± 0.003 | 0.082 ± 0.004 |
| | Calcium (%) | 0.91 1.79 0.54 | 0.65 1.65 0.59 | 0.5 1.2 0.63 |
| | Potassium (%) | 0.28 ± 0.013 * | 0.25 ± 0.007 | 0.24 ± 0.01 |
| Litter Material | Biomass ($g/m^2$) | 656 ± 72 ** | 692 ± 72 | 220 ± 20 |
| | Nitrogen (%) | 1.38 ± 0.03 ** | 1.23 ± 0.036 | 1.05 ± 0.022 |
| | Phosphorus (%) | 0.107 ± 0.002 ** | 0.096 ± 0.003 | 0.084 ± 0.004 |
| | Calcium (%) | 1.87 2.33 1.29 | 1.25 2.55 0.88 | 0.55 1.55 0.7 |
| | Potassium (%) | 0.15 ± 0.005 | 0.14 ± 0.008 | 0.15 ± 0.01 |

+ Because of variation among locations, mean values for calcium are given in order for Tuktoyaktuk, Tununuk Pt. and Reindeer Station. All other values are means and their standard errors from 9 samples

* Difference between hilltop and depression is significant at the 95% level of confidence

** Difference between hilltop and depression is significant at the 99% level of confidence

Frost action at midslope and hilltop positions is greater than in bottom positions. Together with greater mineralization, instability in midslope and hilltop positions prevents cryptogam cover and biomass from accumulating as much as in bottom positions.

## Chemical Composition of Plant Tissue

Nitrogen and phosphorus mean values are significantly different among the three topographic positions in both standing crop and litter. However, standing crop from hilltop positions has significantly different potassium contents from mid and bottom position material (Table 2).

In Table 4, analyses of *Betula nana* spp. *exilis* leaf tissue show significant differences in nitrogen and potassium among topographic positions. This indicates that differences are not due to species change.

Table 4. Chemical composition of *Betula nana* leaf tissue harvested August 26, 1972 at Tuktoyaktuk, Tununuk Pt. and Reindeer Station. (Values represent means and their standard errors for 9 samples)

| | Hilltop | Midslope | Depression |
|---|---|---|---|
| Nitrogen (%) | 1.83 ± 0.065 * | 1.76 ± 0.048 | 1.61 ± 0.047 |
| Calcium (%) | 0.68 ± 0.03 | 0.77 ± 0.04 | 0.63 ± 0.10 |
| Phosphorus (%) | 0.25 ± 0.014 | 0.23 ± 0.014 | 0.22 ± 0.026 |
| Potassium (%) | 0.64 ± 0.022 ** | 0.60 ± 0.026 | 0.53 ± 0.02 |

* Difference between hilltop and depression is significant at the 95% confidence level

** Difference between hilltop and depression is significant at the 99% confidence level

The analyses seem to indicate that nitrogen content of plant and litter material is independent of changes in total or available soil nitrogen. Therefore environmental soil factors such as temperature, moisture, pH, organic layer

thickness, mineral soil available for root penetration, and active layer depths probably determine differences in nitrogen content of plant tissue among the topographic positions. These factors interact to affect the plant's ability to take up nutrients.

Differences in phosphorus and potassium content in plant tissue among topographic positions seems to be correlated with differences in available soil phosphorus and potassium.

Calcium contents of standing crop and litter material indicate differences in material from different topographic positions, but also differences among geographic locations. High calcium contents at Tununuk Point probably are correlated with the relatively high pH there.

Carbon/nitrogen ratios increase from top to bottom positions in standing crop, litter, and surface organic horizon material (Table 5). This indicates high mineralization rates on hilltop positions. Because mineralization rates are slower in bottom positions, total nitrogen reserves in organic material will be higher than hilltops and midslopes (Table 6). Table 6 also indicates the organic layer is the major reservoir of nutrients. However, this reservoir is largely unavailable to living organisms.

Table 5. Carbon/Nitrogen ratios of standing crop, litter and surface organic layer for three topographic positions at Tuktoyaktuk, Tununuk Point and Reindeer Station.

| | Hilltop | Midslope | Depression |
|---|---|---|---|
| Standing Crop Material* | 45:1 | 50:1 | 59:1 |
| Litter Material** | 33:1 | 36:1 | 42:1 |
| Surface Organic Horizon** | 20:1 | 21:1 | 23:1 |

* Assume 50% Carbon in Standing Crop Material

** % Carbon = 0.5 Loss on Igniton %.

Table 6. Total nitrogen reserves of standing crop, litter and organic surface layer in $g/m^2$.

| | Hilltop | Midslope | Depression |
|---|---|---|---|
| Standing Crop Material | 11 | 9.9 | 9.2 |
| Litter Material | 9 | 8.5 | 2.3 |
| Organic Material | 555 | 480 | 645 |

# DISCUSSION

## Soil Characteristics

Soils are a function of at least five interacting factors: climate, animal and vegetable matter, parent material, topography and time. This was Dokuchaev's definition in 1886 and it is still widely accepted today.

In the arctic tundra, where biologically useful soil is found only in the active layer, the physical action of frost becomes a very important factor in determining the degree of soil development. At any one time and place, tundra soil morphology reflects two processes: one process relates to soil formation and involves organic matter production and a mildly acid gley process, the other is the destructive physical force due to frost action above the permanently frozen material (Tedrow, 1966).

## Soil Moisture

Soil moisture in the tundra study area is crucial because of its regulatory effect on soil temperature. Hilltops are generally imperfectly drained, midslopes moderately well-drained and depressions poorly drained. Field moisture values for the hilltop surface horizons are nearly half that of the depressions. Lower moisture contents in top and mid positions permit soil temperatures to reach higher levels

than temperatures in depressions (Younkin, personal communication; Haag, 1972). As a result, the active layer becomes deeper and a greater volume of soil is available for plant root exploration. This greater soil volume also becomes subject to greater stresses during freeze-up in fall.

## Soil Organic Matter

Values shown in Table 1 for organic layer depths are means from 9 samples. However, due to soil movement by frost action, these values take on little meaning in the absolute sense. They represent surface horizon thickness for three topographic positions assuming a landscape with no microtopography. In reality, the surface organic horizon thickness may vary from 0 to 30 cm vertically within the same horizontal distance.

This variation is characteristic only of top and mid positions where the active layer is deep and sufficient mineral soil becomes available in fall during freeze-up for soil movement to take place. In bottom positions, the organic horizon occupies the major volume of the active layer. As a result, this position is not subject to much frost action and the organic horizon remains fairly uniform in thickness.

In top and mid positions the organic horizon often becomes incorporated into lower mineral regions, due to frost activity. This prevents undecomposed organic material from accumulating on the surface, which simultaneously reduces the insulating effect. Higher surface temperatures in top and mid positions than in depressions are a result of lower moisture and lower insulating properties of the surface horizons.

Deeper organic layers are usually associated with decreased organic matter decomposition rates due to lower temperatures when compared to habitats with higher soil temperatures (Vassiljevskaya et al. 1972; Douglas and Tedrow, 1959). Low temperatures slow down decomposition, even though microorganisms in the Arctic are adapted to lower temperatures than in boreal forest soils (Ivarson, 1965). In examining the decomposed status of organic materials in the Tuktoyaktuk, Tununuk Point and Reindeer Station areas, it was found that hilltop and midslope positions had surface horizons composed mostly of mesic and humic materials while bottom position surface horizons were almost entirely fibric in nature. These observations are verified by loss on ignition values which are least in hilltop surface horizons, intermediate in midslope positions and fairly high in bottom positions.

Accumulation of organic matter exceeds decomposition in depression positions for two major reasons, both dependent on the poorly drained condition of the soil. First of all, temperatures remain fairly low throughout the season, which retards the ability of microorganisms to operate efficiently in utilizing the potential energy in the organic-rich materials. Secondly, slow-moving, oxygen-deficient water saturates the profile throughout most of the growing season. The decay of major plant constituents is depressed as the supply of oxygen diminishes and the organic matter then increases. Any oxygen present is soon used by roots or microorganisms so that anaerobic microorganisms alone can survive. If the saturated condition persists, toxic effects on plants and microorganisms are induced because the products of decay and weathering are not carried away rapidly enough.

## Soil and Plant Nutrients

The problem of relating soil and vegetation nutrients is discussed by Cook and Harris, (1950). They found no real soil-plant relationship in a range forage study and reasoned that plants do not assimilate mineral constituents in the same proportion as they occur in the soil because plants have a unique nutrient selective power. This selective power varies from species to species and habitat to habitat.

However, the problem is not overwhelming if the soil nutrient status can be altered by artificial application of fertilizers. Haag (1972) reports natural vegetation yield increases on the Tuktoyaktuk Peninsula with nitrogen fertilization alone in two tundra habitats, but little or no response resulted from application of phosphorus alone. Both nutrient applications resulted in increased uptake of these nutrients by the plants. Younkin (1972) working in the same area with introduced plants on disturbed habitats, found that plant yields were best with phosphorus application alone or in combination with nitrogen. Tamm (1951) analyzed birch foliage in a natural habitat which had been fertilized. Fertilization positively influenced the uptake of phosphorus, potassium and calcium.

In the arctic tundra, soil can be considered to be a largely unavailable nutrient reservoir. Table 6 indicates that large amounts of nitrogen are tied up in organic form in the surface organic layer. Soil analyses (Table 1) indicate that available nitrogen is nearly non-existent and that available phosphorus and potassium are very low.

Because of slow decomposition rates, organic complexes containing essential nutrients are broken down slowly by microorganisms, releasing nutrients at a rate almost too slow to measure. Nutrients, when made available, are used quickly by microorganisms and plants.

Nitrogen

Nitrogen is an essential constituent of proteins and chlorophyll in plants. The forms most commonly assimilated by plants are the nitrate and ammonium ions (Tisdale and Nelson, 1966). Critical nitrogen levels are often expressed in term of carbon:nitrogen ratios because total nitrogen is not a good indicator of available nitrogen (Loach, 1966). In natural materials with approximately 40 per cent carbon, the critical levels corresponding to 1.2 to 1.8 per cent nitrogen are C:N ratios of 20 to 30:1 (Alexander, 1961). Greater ratios favour immobilization, smaller ratios mineralization. Table 5 shows C:N ratios for three topographic positions and three materials. The C:N ratio of the organic horizon for all positions falls within this critical range. A few stands in midslope and hilltop positions at Tununuk Point had C:N ratios below 20:1 while some bottom positions at Tuktoyaktuk had C:N ratios approaching 30:1. Litter material in all positions had C:N ratios too high to be a supplier of available nitrogen to plants. C:N ratios within the surface horizon are sometimes favourable for mineralization by microorganisms, but unfavourable conditions of temperature, moisture and soil reaction in bottom positions might reduce effects of favourable C:N ratios.

In the cool, acid anaerobic conditions of depressions, respiration released the contained nitrogen in the ammonium ion form (Tisdale and Nelson, 1966). This ion is not as easily lost by leaching as the nitrate ion, especially at low temperatures and in material with high cation exchange capacities. In fact, some ions may even be fixed (Borge and Broadbent, 1961). This implie that the predominant form of available nitrogen to the plants would be the nitrate ion in midslope and hilltop positions and the ammonium ion in bottomland positions.

Tables 2 and 4 show that tundra vegetation and litter in the study areas contain a significantly greater per cent nitrogen on hilltops than midslopes and depressions. Because available and total soil nitrogen do not demonstrate this pattern, other factors must influence this consistent trend in vegetation. Table 4 demonstrates that this trend cannot be explained by species change.

The nitrogen-supplying power of the soil per unit volume seems to be similar in all positions. However, a greater volume is available for root exploration in midslope and hilltop positions because of the deeper active layer (Table 1). This indicates that the effect of reduced temperatures, pH and oxygen levels do not seem to be the major factors in reduced nitrogen levels and productivity of depression vegetation when compared to midslope and hilltop vegetation.

*Eriophorum vaginatum* spp. *vaginatum*, which is usually the dominant species in depression positions of the study areas, is efficient in taking advantage of the decreased soil volume. Its roots can explore a large soil volume because of their ability to penetrate the freezing or melting surface of the permafrost surface. Also, *Eriophorum* is efficient in translocating nutrients from leaves to rhizomes and roots, thereby conserving nutrients (Goodman and Perkins, 1959). Goodman and Perkins (1959) believe that the *Eriophorum* tussock is a self-sustaining "island" because of its nutrient retentive ability. Few nutrients are lost when leaves die and decay because of the low concentration of these nutrients in old *Eriophorum* leaves.

## Phosphorus

This major nutrient is required in much smaller amounts by plants than is nitrogen. Phosphorus is taken up by plants mainly in the orthophosphate ion form ($H_2PO_4^-$) and a sufficient supply of the ion seems to aid root growth and protein synthesis (Tisdale and Nelson, 1966).

Soil parent material is responsible for the ultimate supply of phosphorus. Soil analyses indicate very low supplies of available phosphorus in all soils of the study area (Table 1). Availability seems to decrease downslope. Paul and DeLong (1949) indicate that prolonged flooding results in decreased soil phosphorus. This is due to conversion of inorganic phosphorus to organic phosphorus. Glentworth (1947) indicates that, in the gley zone of the soil profile, phosphorus is highly soluble and so is readily lost. As a result, the total phosphorus content in the gley zone is decreased.

Loach (1968) found nutrients to be higher in a heath site than a valley bog in the British Isles. Additions of phosphorus improved growth more than additions of nitrogen and potassium. He found that waterlogging in the valley bog impairs the ability of roots to absorb nutrients due to low oxygen and high carbon dioxide concentrations which restrict root growth to upper horizons. Gore (1961) found that phosphorus or calcium were not limiting factors in an *Eriophorum* meadow in the British Isles. In his investigations, Armstrong and Boatman, 1967) found that oxygen concentration influenced phosphorus availability and uptake. In low oxygenated or waterlogged acid soils, ferrous ions precipitate with phosphorus in and around oxygen rich roots of plants, preventing phosphorus uptake (Armstrong and Boatman, 1967; Pearsall, 1950; Humphries, 1962).

Korovin *et al.* (1963) indicated that phosphorus deficiency in plants on cold soils has a negative effect on high energy bond formation. A phosphorus deficiency slows

down sugar-acid acceptors so that the ammonium ion becomes tied to organic compounds and is of little use in protein synthesis. Korovin et al. (1963) also found that a temperature drop is accompanied by a suppression of phosphorus absorption and incorporation into proteins.

This study agrees with data of Laughlin (1969), showing that available soil phosphorus may possibly influence nitrogen uptake and nitrogen content of standing crop material A small change in available soil phosphorus (2 to 3 ppm) is accompanied by large changes in standing crop nitrogen and phosphorus, although other factors probably influence these changes to some extent.

### Potassium

Potassium, like phosphorus, originates in parent material. It is absorbed by plants as the potassium ion. It does not form an integral part of plant constituents, but its function appears to be catalytic.

Available potassium decreases downslope in the three study areas. This change is not evident in potassium content of plant material, except for *Betula* leaves, in which it shows a significant decrease from hilltop to depression.

Potassium has catalytic functions in plant physiology, and so may have some effect on protein synthesis and may be partly responsible for a decreasing protein or nitrogen content of plant material from hilltops to depressions.

## IMPLICATIONS

1. Soil analyses give extremely variable results so that a great number of samples are required in order to provide some measure of confidence in the data. Plant material analyses, on the other hand, give very consistent results with little variability.

2. The data agree in general with other studies. Plant nutrient differences among habitats are significant within the study areas, and this could affect animal habitat preferences and behavior.

3. Most of the total nutrient pool is contained within the organic layer. If these nutrients are not retained by replacing the organic mat after surface disturbance, considerably more fertilizer will be needed to replace these losses.

4. Bottom lands or depressions appear to be less sensitive to natural disturbances than slopes or hills. This is probably due to the greater depth of fibric organic matter in depressions and to the lesser volume of mineral material.

5. Depressions when disturbed will probably require higher rates of fertilization to overcome nutrient deficiencies than will slopes and upland sites.

Implications Nos. 4 and 5 are impressions developed during the study. More field work is necessary to substantiate them.

## NEEDS FOR FURTHER STUDY

Research on decomposition rates within the study areas would aid in a better understanding of nutrient cycling.

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## SUMMARY

Field studies were done at three locations east of the Mackenzie Delta in 1971-72. Loss on ignition, field moisture, water retention and thickness of the surface organic layer are greatest in depressions and least on hilltops while the active layer depth, surface organic density and pH are greatest on hilltops and least in depressions. Available and total soil nitrogen are no different on hilltops than depressions, but available soil phosphorus and potassium are significantly greater on hilltops than depressions. Standing crop and litter nitrogen and phosphorus are significantly greater on hilltops than depressions. Leaf, stem and litter mass is greatest on hilltops and least in depressions while cryptogam mass is greatest in depressions and least on hilltops.

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# AUTECOLOGICAL STUDIES OF NATIVE SPECIES POTENTIALLY USEFUL FOR REVEGETATION, TUKTOYAKTUK REGION, N.W.T.

by
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## INTRODUCTION

Oil exploration in the Mackenzie Delta region has resulted in a number of man-induced soil and vegetation disturbances. Most of these are concerned with the construction of seismic lines and roads which have resulted in the breakage and compaction of the vegetation mat. This kind of disturbance can be considered an accelerated natural disturbance and is distinct from that which would occur from an oil spill or other chemical perturbation. A great number of the seismic lines and roads criss-cross the delta region amounting to many acres of disturbed tundra. Stimulated by the knowledge that greater development and possible damage might occur with the construction of oil and gas pipelines, government and industry have sought means of reducing and repairing any future damage.

I began my revegetation research in 1970. The objectives of the first studies were: 1) to identify species which would quickly cover disturbed areas, thereby restoring the natural energy budget and minimizing the effects of permafrost meltout, and; 2) to restore the tundra ecosystem, as far as was practicable, to its natural state. The species used in these early experiments were agronomic grasses primarily of boreal and temperate origin which had shown a tolerance to northern environments and of which there was a readily available seed supply.

Subsequent research (Younkin, 1972) has shown that several of these agronomic grasses will provide good cover and survive for at least one or two winters and in this sense satisfy the first objective. However, their ability or desirability in satisfying the second objective is unclear. None of the species tested is found on the Tuktoyaktuk Peninsula and therefore is not a normal part of the ecosystem. Their long term effects on animal populations and native plant communities is not fully known. Will they continue to survive in this region or will diseases or an unusual winter or summer kill them off? These are questions which will probably not be answered until after the first massive seedings have taken place. The magnitude of the projected disturbance in any pipeline project and the large amounts of seed needed to repair the damage dictate that these agronomic species must be

used. It seemed prudent, however, to investigate the revegetation potential of species naturally occurring in the tundra and northern boreal forest to determine their potential usefulness in seed mixes.

Preliminary research (Hernandez, 1972) indicated that on disturbed sites certain species invade faster than others. Predominant among these were grass species in the genera Arctagrostis, Calamagrostis, Poa and Festuca and several forbs including Senecio and Epilobium. Because of the number of colonizing species, it was not possible to study all in detail. However, general field observations suggested that two grasses, Arctagrostis latifolia and Calamagrostis canadensis, were the most important colonizers. These, along with other selected native species, were studied both in the laboratory and field during the past year. The objectives of the present research are twofold: 1) to assess the revegetation potential of selected native grass species observed to be naturally reseeding disturbed areas, and; 2) to characterize the differences in microenvironment between disturbed and adjacent undisturbed tundra.

The ability of a plant species to invade and become established in a new area is dependent upon a number of factors: availability of seed, seed dispersal patterns, seed viability and germination, seedling establishment, and growth to maturity including reproduction. To a limited extent all of these factors were studied during the past two years. However, certain aspects were deemed more important to this study than others and have been emphasized. The following includes discussion of taxonomy and range, distribution and importance in disturbed and undisturbed tundra communities and selected aspects important to the colonization potential of the two species, including a brief description of micro-environmental changes due to disturbance.

## TAXONOMY AND RANGE

Both genera, Arctagrostis Griseb. and Calamagrostis Adans., are common in the cool to cold regions of the northern hemisphere and contain species which are circumpolar in distribution. Arctagrostis is a more truly northern genus, having no species occurring below 50°N (Klebesadel, 1969) while Calamagrostis has species which are found as far south as 22°N (Hitchcock, 1950).

## Arctagrostis

Arctagrostis is a genus of little taxonomic differentiation, and, although 17 species have been described at one time or another (Tolmachev, 1964), only two to three are recognized on a world-wide basis. Hultén (1968) recognizes two species: 1) *A. latifolia* (R.Br.) Griseb. circumpolar and containing three varieties -- *A. latifolia* var. *latifolia*, the more northern circumpolar form and the subject of this report, *A. latifolia* var. *arundinacea* and *A. latifolia* var. *angustifolia*; and 2) *A. poaeoides* Nash. The Russian author, Tolmachev, (1964) recognizes *A. latifolia* but considers it to be only weakly differentiated throughout its range and containing at best only one subspecies *A. latifolia* spp. *gigantea* (Turez ex. Griseb.) Tzvel. occurring in the mountain ranges of eastern Siberia. For the purposes of this report the taxonomic treatment of Hultén (1968) will be followed.

*A. latifolia* var. *latifolia* is a relatively tall perennial grass found almost entirely in arctic regions. Its range is circumpolar and, in the western hemisphere extends from approximately 60°N to about 80°N on Ellesmere Island (Hultén, 1962). In the U.S.S.R. this range is extended southward to 50°N along mountain ranges of eastern Siberia. The species exhibits a tolerance to a wide range of tundra conditions and is found as a common but unimportant member of many tundra communities (Tolmachev, 1964). It ranges in height from 20 to 50 cm in the Arctic islands (Porsild, 1957) to over 100 cm in the Tuktoyaktuk Peninsula. It has broad leaves 0.5 to 1 cm in width and generally stout culms, spreading by means of stout branching rhizomes.

## Calamagrostis

In comparison to *Arctagrostis*, the genus *Calamagrostis* is widely differentiated containing over 100 species (Tolmachev, 1964) which occupy a wide range of habitats over much of the northern and southern hemispheres. The majority of species in the northern hemisphere are restricted to temperate or boreal regions, only 10 being found in the Arctic. Of these, *Calamagrostis canadensis* (Michx.) Beauv. is probably one of the more important, forming extensive stands in southern and southcentral Alaska which are used for forage (Mitchell and Evans 1966) and in boreal and arctic parts of western Canada where it comes in densely after fire or logging, thus aiding erosion control. Nygren (1954) considers this to be the most successful of the New World species.

*C. canadensis* subsp. *canadensis* is restricted to North America but has a wide north-south range extending from near 35°N in Arizona mountains to 69° at Tuktoyaktuk, N.W.T. It appears to have a large ecological amplitude occurring in

a variety of habitats ranging from lowland wet sites to windswept alpine ridges (Mitchell, 1968). In general morphology this species is similar to *Arctagrostis latifolia* and at times is easily confused.with it, having culms up to 1 m tall and leaves 3 to 8 mm wide (Hultén, 1968).

### Past History

According to Hulten (1937) *A. latifolia* is a truly circumpolar Arctic-montane species which is believed to have spread from the mountains of northeast Asia to North America before the last glaciation. It did not reach the southern rim of the ice but was trapped to the north of the ice refugia where its spreading capacity was contained and its ecological amplitude reduced by the isolation and selection pressure imposed by the glacial period.

*Calamagrostis canadensis* is believed to have arisen from members of the circumboreal flora (Hultén, 1937). These species, partially due to their intolerance to cold, did not reach the northern limits of the ice but were contained in large refugia and involutions in the ice sheet. Here they were not as genetically isolated and, through interbreeding and recombinations, retained their spreading ability and ecological amplitude. Today most of the widespread plants of the Arctic and boreal belts belong to this latter relatively broadly-adapted group.

## OCCURRENCE AND IMPORTANCE IN TUNDRA COMMUNITIES

### Undisturbed Communities

Corns (1972) and Hernandez (1972) in separate investigations of plant communities occurring in the region of Tuktoyaktuk found *Arctagrostis latifolia* and *Calamagrostis canadensis* as a common but minor component of almost all plant communities studied. It was not possible, however, to determine from their data, which was based upon cover, the relative importance of these two species in various community and habitat types. Information of this kind was needed to assess both the magnitude of the available seed source and to determine as nearly as possible the natural habitat preference and performance of the species.

## Methods

The study was begun in mid-August 1972 when most grass species were in flower. Stands were selected in such a manner as to include a variety of community and habitat types, often working on a moisture gradient from lowlands to uplands. Each stand was placed into topographic and soil drainage classes according to the Canadian Department of Agriculture soil classification system (1970). Dominant species were identified in each layer of the vegetation and later this information was used to classify the communities according to Corns (1972). Within each stand a 5 X 10 m sample area was marked out. By pacing back and forth at one meter intervals, counts were made of vegetative and flowering clumps of selected species. It is recognized that, in most cases, clumps were joined by rhizomes and were therefore not truly separate individuals. This was not important to the purpose of this study and was ignored. The depth of the active layer was measured at 10 points within the sample area, using hummock centers as the point of reference in hummocky tundra.

## Results

The results are summarized in Table 1. *Calamagrostis canadensis*, though appearing to be absent in most communities, is in actuality more widely dispersed in the tundra than *Arctagrostis latifolia*. It occurred in all the communities except the sedge, reaching its greatest importance in well-drained birch heath communities. In no community, however, was it very vigorous, generally appearing chlorotic and producing very few seed heads. Because of its non-distinctive vegetative appearance and the general absence of seed heads, it is easily overlooked.

*Arctagrostis latifolia*, common in tundra communities of all topographic positions which are imperfectly to moderately well-drained, is most important on imperfectly-drained areas with moist to mesic soils and less important on dry upland or wet lowland sites. It seldom occurs on soils with a seasonal active layer depth of less than 35 cm and appears to favour areas where the mineral soil is covered by only a thin layer of peat. Seed head production was greatest on moist to mesic sites. In general, the vigor of this species was good in all areas of occurrence.

Many of the other less important colonizing species such as *Epilobium angustifolium* and *Senecio congestus* are rarely found in undisturbed tundra communities: only *Petasites frigidus*, of nearly equal importance to *Arctagrostis*,

| PHYSICAL SITE CHARACTERISTICS | | | | | MEAN NUMBER OF INDIVIDUALS AND NUMBER IN FLOWER PER STAND | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Topographic Class | Soil Drainage Class | Mean Active Layer Depth (cm) (8-15 Aug) | Community Subgroup | Number of Stands | *Arctagrostis latifolia* | | *Calamagrostis canadensis* | | *Poa lanata* | | *Festuca brachyphylla* | |
| | | | | | Total | Flower | Total | Flower | Total | Flower | Total | Flower |
| Depressional | Poor | 30 ± 2 | Sedge | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nearly level | Imperfect | 26 ± 1 | Sedge-Cotton-grass-Heath | 6 | .3 | 0 | 35 | 0 | 0 | 0 | 0 | 0 |
| | Well drained | 27 ± 1 | Raised Center Polygon | 6 | 3 | 1 | 7 | 4 | 0 | 0 | 0 | 0 |
| Very gently sloping | Imperfect | 43 ± 3 | Alnus | 3 | 46 | 12 | 72 | .3 | 1 | 1 | 0 | 0 |
| Gently sloping | Imperfect | 44 ± 1 | Birch-Willow-Heath | 5 | 61 | 22 | 58 | 0 | 1 | 1 | 0 | 0 |
| Moderately sloping | Moderately well drained | 47 ± 2 | Birch-Willow-Heath | 6 | 11 | 1 | 59 | 0 | 2 | 2 | 1 | 1 |
| Strongly sloping | Well drained | 49 ± 1 | Birch Heath | 4 | 0 | 0 | 67 | 0 | 9 | 9 | 1 | 1 |
| Hill top | Well drained | 42 ± 1 | Birch Heath | 4 | 0 | 0 | 115 | 0 | 4 | 4 | 1 | 1 |

Table 1. Relationship of physical site characteristics to mean number of individuals and number of flowering heads of selected species.

being found in the same habitats. Although it has good dispersal mechanism and its seeds germinate readily at field temperatures, nearly every head examined had been attacked by moth larvae destroying most of the seeds. Of the remaining grasses, _Poa lanata_ and _Festuca brachyphylla_ are restricted to drier sites where they are of very low importance. That they prefer drier sites is also suggested by their greater importance in well-drained, disturbed areas.

Discussion

of the two important grasses, _Calamagrostis canadensis_ appears to have the wider ecological amplitude, being able to survive both on shallowly or deeply thawed soils and in moist to dry conditions. It is found on mineral and organic soils but is more frequently found on peaty soils or in peaty areas between hummocks or frost boils. That this species has such a wide ecological amplitude is not unexpected from the wide extent of its range. Its lack of vigor, however, (as denoted by its inability to produce flowering heads) suggests that on the undisturbed tundra, conditions are approached which are near its limits of tolerance so that its continued existence is dependent upon tundra disturbances which provide a suitable habitat, or else that it is not a vigorously competitive species.

_Arctagrostis latifolia_ has a narrower range of tolerance being most important in mesic to moist environments and being restricted to soils with an active layer of greater than 35 cm. This species is generally not found growing on deep organic soils. It produces seed heads in all areas of occurrence and numerous seed heads in more favourable areas. This, along with its generally vigorous appearance and the limitation of its range to northern areas, suggests that it is the more highly adapted of the two species to arctic environments.

## Disturbed Communities

Hernandez in 1970 and 1971 surveyed a number of disturbed sites in the Mackenzie Delta resulting from oil exploration. Of these disturbances, the seismic lines constructed in the summer of 1965 were the most severe, resulting in the removal of all vegetation and soil down to permafrost. In almost all cases rhizomes and root systems were entirely removed so that any revegetation which took place was the result of seeding from the adjacent tundra. Comparisons of composition and cover between adjacent disturbed and undisturbed communities provide insights into the relative abilities of different species to invade and establish in disturbed areas.

| Species | COMMUNITY TYPES | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dwarf Shrub Heath %cover | ratio | Dwarf Shrub Heath %cover | ratio | Dwarf Shrub Heath %cover | ratio | Dwarf Shrub Heath %cover | ratio | Eriophorum vaginatum Meadow %cover | ratio | Sedge Meadow %cover | ratio | Sedge Meadow %cover | ratio |
| Arctagrostis latifolia | 5.6 | 1:28 | 14.6 | 1:73 | 7.8 | 1:39 | 5.7 | 1:29 | 1.5 | 1:7.5 | - | - | - | - |
| Calamagrostis canadensis | 9.5 | 1:47 | 7.6 | 1:76 | 6.8 | 1:34 | 6.6 | 1:33 | - | - | - | - | - | - |
| Poa lanata | 6.2 | 1:31 | 2.0 | 1:10 | 1.3 | 1:6.5 | 0.7 | 1:3.5 | - | - | - | - | - | - |
| Carex Bigelowii | 6.6 | 1:2 | 1.7 | 1:17 | 2.3 | 1:11.5 | 13.0 | 1:3.7 | 0 | 0 | - | - | - | - |
| Arctophila fulva | - | - | - | - | - | - | - | - | 32.5 | 1:162 | 8.4 | 1:42 | 13.1 | 1:65 |
| Carex aquatilis | - | - | - | - | - | - | - | - | - | - | 3.8 | | 7.6 | |
| Eriophorum vaginatum | - | - | - | - | - | - | - | - | 5.4 | 1:.31 | - | - | - | - |
| Betula nana | 0.5 | 1:.04 | 1.3 | 1:.13 | 0 | *1:- ∞ | 0 | 1:- ∞ | - | - | - | - | - | - |
| Salix glauca | 1.0 | 1:.09 | 3.9 | 1:.43 | 0 | 1:- ∞ | 0.7 | 1:.33 | - | - | - | - | - | - |
| Lupinus arcticus | 0.1 | 1:.03 | 0.2 | 1:.07 | 0 | 1:- ∞ | 0 | 1:- ∞ | - | - | - | - | - | - |
| Vaccinium uliginosum | - | - | 0 | 1:- ∞ | 0 | 1:- ∞ | - | - | - | - | - | - | - | - |
| Vaccinium vitis-idea | 0 | 1:.01 | 0 | 1:- ∞ | 0 | 1:- ∞ | 0 | 1:- ∞ | 0 | 1:- ∞ | - | - | - | - |
| Dryas integrifolia | - | - | - | - | - | - | 0 | 1:- ∞ | - | - | - | - | - | - |
| Rumex arcticus | - | - | - | - | - | - | - | - | 0.6 | 1:3 | - | - | - | - |
| Moss | 2.0 | 1:.09 | 19.6 | 1:.09 | 13.6 | 1:.26 | 1.8 | 1:.06 | 6.4 | 1:.21 | 9.2 | 1:.26 | 5.0 | 1:.26 |

*In instances where species important in the undisturbed tundra were absent in the disturbed tundra, the ratio of change was infinite and is expressed as - ∞.

Table 2. Percent cover in disturbed areas and ratio of cover changes from undisturbed tundra of species occurring in 1965 summer seismic lines passing through various community types in the Tuktoyaktuk Peninsula.

## Methods

Eight stands were studied along 1965 seismic lines in the Tuktoyaktuk region (Hernandez, 1972). Five of these were in dwarf shrub-heath tundra, two in wet sedge meadows and one in cottongrass-dwarf shrub tundra. At each stand, composition and cover of plant communities in both disturbed and adjacent undisturbed tundra was measured (Table 2). Per cent cover is shown for those species occurring in the disturbed area along with the ratio of cover change from undisturbed to disturbed tundra. This ratio was determined by dividing the cover values from the undisturbed tundra into those from the disturbed site. This results in a value of one for the species in the undisturbed tundra and some value, either larger or smaller, in the disturbed tundra. A species in the disturbed tundra with a value of less than one is a "cover decreaser" while one with a value of greater than one is a "cover increaser".

## Results

1965 seismic lines running through dwarf shrub-heath communities have four species which are cover increasers: *Arctagrostis latifolia*, *Calamagrostis canadensis*, *Poa lanata* and *Carex bigelowii* (Table 2). All of these except *Carex bigelowii* are of very low cover value in the undisturbed tundra, generally being less than .5 per cent. *Carex bigelowii* has a cover in the undisturbed tundra which ranges from .5 per cent to 3.3 per cent. *Arctagrostis latifolia* and *Calamagrostis canadensis* are the most important increasers providing the most cover and having the highest cover ratio changes. The species important in the undisturbed tundra, such as *Betula nana* and *Salix glauca* have very low cover values in disturbed areas ranging from 0 to 4 per cent.

The remaining disturbed communities are more moist. These sites have fewer species able to establish and are dominated by *Arctophila fulva*, a grass species which is essentially absent in the adjacent undisturbed tundra.

## Discussion

Species common in the undisturbed tundra, such as *Betula*, *Salix* and *Eriophorum*, have the least ability to reinvade and colonize disturbed areas. Seed production and dispersal is not a problem for any of these species, and it is safe to say that seeds from these species must virtually shower down on disturbed sites. The species most important in disturbed areas, *Calamagrostis* and *Arctagrostis* on mesic to dry sites and *Arctophila fulva* on wet sites, are scarce in the native tundra. Though dispersal mechanisms of each of these are probably as good as any of the important native

tundra species, the total amount of seed produced is far lower. This would lead one to speculate that the failure of the important native species to invade disturbed areas lies either in their inability to produce viable or easily germinated seed, in their inability to establish as seedlings, or both. Considering the small seed supply, available colonizing species must provide both a highly viable seed supply and have the ability to establish once the seeds germinate.

## SEED PRODUCTION

In undisturbed tundra communities approximately 30 per cent of the *Arctagrostis* shoots produce seed heads and each head contains 75 to 100 seeds. In disturbed sites 70 to 80 per cent of the shoots produce seed heads, each containing 300 to 600 seeds. When grown from seed in experimental plantings at Tuktoyaktuk, flowering heads were not produced until the second year. The timing of seed shatter for *Arctagrostis* is variable but generally occurs between the last week in August to the middle of September. Shatter is usually 90 to 95 per cent complete. Remaining seeds overwinter successfully and have a germination percentage of 80 to 90 per cent.

In the undisturbed tundra generally less than 5 per cent of the *Calamagrostis* shoots produced seed heads compared to approximately 35 per cent in the disturbed areas. Seed production in either location is quite variable ranging from 0 to 150 seeds per head. Although *Calamagrostis* flowers at about the same time as *Arctagrostis* (mid-August) it does not set seed and shatter until mid to late September. The fruits remain attached to the palea and lemma which disarticulate from the glumes. A hairy callus aids in the wind dispersal of the fruits.

## SEED GERMINATION

The severe climatic conditions in the arctic have led many investigators in the past to infer some universal form of seed dormancy as a protective mechanism (Billings and Mooney, 1968). However, studies by several authors (Sorensen, 1941; Bliss, 1958) have shown that, given adequate moisture and heat, seeds of many arctic species will germinate quite readily. Most of these germination experiments have been carried out under standard laboratory conditions on moist filter paper and at room temperature. The ability to germinate under these relatively favourable conditions tells little

about the response of a species to the generally much less favourable tundra environment where heat and surface moisture are often limited. The objective of this series of experiments was to assess the recolonization potential of various species by determining their response in per cent and rate of germination to a range of temperature and moisture conditions.

## Temperature

Because of the short growing season with low temperatures, a lack of heat is often considered as one of the more important factors limiting growth and reproduction of all but a relatively few species in the Arctic (Bliss, 1962). While heat is important to the proper functioning of all living organisms, different plant structures have different cardinal temperatures (Daubenmire, 1967). Mature plants of many species can begin or continue to function at temperatures below that necessary for seed germination.

Most tundra plants are known to reproduce by means of rhizomes while seed production is relegated to a position of minor importance (Johnson, 1969; Bliss, 1971). That this is not true for all arctic species is shown by the number of species which are able to reinvade completely denuded tundra areas. The objective of these experiments was to determine the effect of temperature and, to a lesser degree, habitat on the per cent and rate of germination of selected native and agronomic species.

### Methods

Species selected for study fell into one of three categories: 1) important colonizers of disturbed sites; 2) important tundra species providing a large seed source; 3) agronomic species which had been successful in previous revegetation studies. After collection, fruits were air-dried and stored in paper bags at room temperature. Prior to use the fruits were cleaned, removing glumes, lemmas and paleas on all grasses except the fescues. The lemma and palea are tightly affixed to fruits of species in this genus and are a part of the germinating seed under natural conditions. It was determined that the presence of the lemma and palea did not significantly affect germination determinations.

Seeds were germinated within six months of collection on a specially designed seed germination bar which provided a temperature range from 5°C to 20°C. None of the seed was pretreated prior to germination but was placed in aluminum containers lined with filter papers. The containers were placed on the bar at 5°C, 10°C, 15°C and 20°C. The temperature within the trays was monitored with thermocouples and maintained

| Species | Year and location collected | Site | Number of Replicates | 20°C % | 20°C rate | 15°C % | 15°C rate | 10°C % | 10°C rate | 5°C % | 5°C rate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arctagrostis latifolia* | 1971 Tuk* | 65 cutline | 9 | 82±5 | .41±.04 | 87±3 | .25±.01 | 86±3 | .21±.01 | 80±5 | .06±.00 |
| *Arctagrostis latifolia* | 1971 Tuk | Shrub-Heath | 9 | 64±6 | .28±.01 | 69±8 | .20±.02 | 63±5 | .13±.00 | 41±7 | .04±.00 |
| *Calamagrostis canadensis* | 1970 Inuvik | Fireguard | 4 | 81±4 | .29±.01 | 45±3 | .19±.01 | 28±5 | .11±.01 | 19±4 | .06±.00 |
| *Festuca brachyphylla* | 1972 Tuk | 65 cutline | 3 | 91±3 | .07±.00 | 93±1 | .07±.00 | 86±3 | .04±.00 | 8±3 | |
| *Poa lanata* | 1972 Tuk | 65 cutline | 3 | 99±1 | .25±.00 | 97±1 | .19±.00 | 96±2 | .11±.00 | 92±0 | .05±.00 |
| *Festuca rubra* (Arctared) | 1971 Agronomic | | 3 | 92±2 | .33±.00 | 88±2 | .21±.00 | 84±5 | .14±.00 | 56±6 | .06±.01 |
| *Poa pratensis* (Kentucky Blue) | 1971 Agronomic | | 2 | 92±4 | .28±.00 | 96±0 | .22±.01 | 86±6 | .12±.00 | 72±0 | .05±.00 |
| *Eriophorum vaginatum* | 1971 Tuk | Tussock tundra | 4 | 26±2 | .10±.00 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Carex Bigelowii* | 1971 Tuk | Sedge-Cottongrass | 3 | 3±1 | | | | | | | |
| *Betula nana* | 1971 Tuk | Shrub-Heath | 3 | 25±2 | .16±.01 | | | | | | |

* Tuktoyaktuk

Table 3. Mean percent and rates of germination of selected species as affected by temperature. Percent germination is based on the number germinated at the end of 35 days. Rates are based on time required to germinate up to 15 seeds, 1 being the fastest possible rate.

at the desired temperature ±1°C. Distilled water was added to keep the seeds moist and continuous lighting (250 ftc) was provided by a bank of fluorescent lights. Seeds were checked every second day and those that had germinated were removed. A seed was considered germinated when the coleorhiza appeared. Per cent germination was based on the number of seeds which germinated at the end of 35 days. Rate calculations were based on the time required to germinate up to 15 seeds (Dubetz, *et al*. 1962). Fifteen was decided upon as in most of the experiments at least this many germinated.

## Results

The important tundra species *Eriophorum vaginatum*, *Carex bigelowii* and *Betula nana* have a low per cent and slow rate of germination at 20°C. Only *Eriophorum* was tested at lower temperatures but showed no germination below 20°C (Table 3). At 20°C *Poa lanata* and *Festuca brachyphylla* had the highest per cent germination of the native grasses. Germination of *Poa lanata* did not change markedly as temperature decreased, but that of *Festuca brachyphylla* dropped abruptly at 5°C. This may not have been a true drop as the test was terminated at 35 days, and the slow rate of germination, as exhibited by *Festuca brachyphylla* at higher temperatures, may have prevented complete germination. The two agronomic grasses tested showed a high germination percentage at all temperatures although there was a significant drop for both at 5°C. *Arctagrostis latifolia* and *Calamagrostis canadensis* collected from disturbed areas had a similar per cent germination at 20°C. While the germination per cent of *Arctagrostis* remained relatively constant at all temperatures, that of *Calamagrostis* dropped off greatly with each decrease in temperature. The per cent germination of *Arctagrostis* collected from disturbed areas was significantly greater at all temperatures than that collected from adjacent undisturbed tundra. A recent analysis of plant tissue from undisturbed and adjacent disturbed sites suggests that it may be due to a greater nutrient availability on disturbed areas.

The rate of germination of seeds of all species decreased with temperature, the largest decreases taking place between 10°C and 5°C. Of the grasses, germination was slowest in *Festuca brachyphylla* and fastest in *Arctagrostis latifolia* from disturbed sites. The most significant increase for Arctagrostis was at 10°C where it exhibited a rate nearly twice as fast as all other species. The remaining grasses had rates which were similar though slower than those of *Arctagrostis*.

Moisture

For plants in the Low Arctic soils, moisture is seldom a limiting factor, although surface soils may dry considerably especially in well-drained upland sites. Seeds, if they are to successfully germinate on these sites, must have the ability to do so under low or fluctuating water conditions or be able to lie dormant until sufficient moisture becomes available. The objective of this series of experiments was to determine the ability of native and agronomic grass species to germinate under a range of moisture conditions.

Methods

To simulate conditions of physiological aridity, different concentrations of Mannitol solutions were used (Uhvits, 1946). Mannitol is a non-abrasive chemical which is not rapidly assimilated by living organisms.

Three water potentials were selected, $\psi$-0, $\psi$=-3 bars and $\psi$=-6 bars. Water potential is a measure of the potential energy of water in a solution against that of pure water. The more energy the water has (i.e. the purer the water), the greater the tendency for it to move from one area to another as into a germinating seed. A $\psi$=0 bars is represented by distilled water and has the greatest potential energy whereas $\psi$=-6 bars has the least amount of energy and represents the driest of the 3 conditions.

Seeds were cleaned in the same manner as in the previous test and placed in Petri dishes with equal amounts of the appropriate solutions. Each Petri dish was weighed to the nearest 0.01 g. To insure that solutions did not change concentration as water evaporated or was taken up by the seeds, each dish was weighed every two days and brought back up to the original weight by the addition of distilled water. No Petri dish lost more than .5 ml during these periods.

All samples were placed in a seed germinator at 20°C with continuous lights. To further reduce moisture loss while allowing adequate gas exchange, all Petri dishes were placed in polyethylene bags. Germinated seeds were counted every second day. Each test ran 35 days. The remaining ungerminated seeds were then rinsed with distilled water and placed back in the seed germinator for another 25 days. Counts were made of the number germinated and added to the previous germination counts to calculate total per cent germination.

Results

All species showed at least a slight decrease in per cent germination as water potential decreased (Table 4). Poa

| Species | Year and Location Collected | Site | WATER POTENTIAL ψ — Control ψ=0 Bars | | ψ= -3 Bars | | | ψ= -6 Bars | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | % | rate | % | rate | %Total | % | rate | %Total |
| _Arctagrostis_ _latifolia_ | 1972 Tuk | 65 cutline | 96±4 | .35±.01 | 67±6 | .25±.01 | 76±2 | 24±4 | - | 56±4 |
| _Calamagrostis_ _canadensis_ | 1971 Inuvik | Fireguard | 81±1 | .23±.00 | 76±6 | .28±.02 | 76±6 | 27±3 | - | 30±1 |
| _Poa_ _lanata_ | 1972 Tuk | 65 cutline | 99±1 | .25±.00 | 95±5 | .29±.01 | 96±2 | 91±1 | .28±.01 | 97±2 |
| _Festuca_ _brachyphylla_ | 1972 Tuk | 65 cutline | 91±3 | .07±.00 | 0 | 0 | 99±1 | 0 | 0 | 91±1 |
| _Festuca_ _rubra_ (Arctared) | 1971 Agronomic | | 88±0 | .35±.00 | 89±6 | .31±.01 | 92±2 | 85±3 | .28±.00 | 92±2 |

Table 4. Mean percent and rates of germination of selected species as affected by the water potential of germination solution. Percent total germination represents that occurring after the solutions were rinsed off and distilled water applied. All data are based on 3 replications of 25 seeds each.

lanata and the agronomic Festuca rubra, had the highest per cent germination under all treatments and showed little decrease in germination as water $\psi$ decreased. Festuca brachyphylla was the most dramatically affected by water potential, ceasing to germinate at -3 bars.

Of the two important colonizing species, Calamagrostis canadensis was the least affected by decreasing water potentials. Though in the controls it had a lower germination per cent than Arctagrostis, it was little affected by -3 bars. At -6 bars, however, its per cent germination dropped by more than half. Arctagrostis latifolia was significantly affected by all decreases in water potential, dropping by one third at -3 bars and by two thirds at -6 bars. Because of its initially higher germination in the controls, however, its germination per cents at -3 and -6 bars were similar to those of Calamagrostis.

Festuca rubra and Poa lanata provided the most consistently high rates of germination, being little affected by decreasing water potentials. The rate of germination of Poa lanata was, in fact, somewhat stimulated by lower water potentials as was that of Calamagrostis canadensis. At $\psi$=0 bars, Arctagrostis latifolia and Festuca rubra had the fastest rates of germination. At $\psi$=-3 bars, Arctagrostis and Calamagrostis had similar rates, but at $\psi$=-6 bars, not enough seeds of either species had germinated to enable the rate of germination to be measured accurately.

Per cent total germination was used as a measure of a species' ability to experience drought conditions and then to germinate when adequate moisture was available. All of the species tested showed some ability to recover from drought and germinate. The magnitude of this ability, however, was a function of how greatly seed germination had been retarded by the initial drought. Poa lanata and Festuca rubra were little affected by drought and therefore had only a slight increase in per cent total germination over the initial germination. Arctagrostis latifolia showed increases over initial germination at both $\psi$= -3 and -6 bars, while Calamagrostis canadensis showed none. Festuca brachyphylla showed the most significant increases, increasing at both $\psi$= -3 and -6 bars from zero germination to over 90 per cent.

## Discussion

The results of this series of tests suggest that germination is one of the key factors determining the species which will eventually become established in a disturbed area. Of the three species tested that are important in the native tundra, all had small percentage and rates of germination at 20$^{o}$C. The one species tested at lower temperatures, Eriophorum

vaginatum, showed no germination and there is no reason to suggest that the others would respond differently. Wein (personal communication) testing Eriophorum vaginatum populations from Inuvik, N.W.T. and near the lower Rat River, Y.T., found per cent germination of 60 per cent and 70 per cent respectively at 20°C but found that at temperatures below 20°C germination was almost zero. It was also noted that over a period as short as three months, the viability of the seed decreased significantly.

All of the species commonly found in disturbed areas had relatively high per cent and rates of germination at all temperatures tested. Billings and Mooney (1968) reported that to the best of their knowledge only one tundra species had been reported which could germinate at a continuous temperature of 5°C. In this study all of the colonizing species were able to germinate at 5°C. Arctagrostis latifolia, an important grass species in disturbed areas, had one of the most complete and rapid germinations of all native species. Only Poa lanata had a higher per cent germination, but its rate was consistently lower than that of Arctagrostis. The two agronomics tested, Festuca rubra and Poa pratensis, also had high rates and percentages of germination, suggesting one of the reasons for their success in previous revegetation studies. That they are able to do so well in arctic environments is not totally unexpected as Festuca rubra is a native species found throughout the Arctic and Poa lanata is an introduced weed which already has acquired a circumpolar distribution (Hultén, 1968).

Under conditions of increasing aridity many of the native species tested showed a separation of germination ability along habitat lines. Poa lanata, a common species in well-drained native and disturbed sites, was essentially unaffected by aridity, maintaining a complete and rapid germination under all conditions tested. Another species more common in drier areas, Festuca brachyphylla, did not germinate at all under water stress. However, when fresh water was added,over 90 per cent of the seeds germinated suggesting that it could survive periods of drought and still remain viable. Arctagrostis latifolia, generally found in moist to mesic sites, showed a steady decline in per cent germination as water stress increased. Its recovery was fair as the per cent total germination in all cases was over 50 per cent. Calamagrostis canadensis, which tolerates a wider range of habitats than does Arctagrostis, was less affected by aridity, and, in fact, its rate of germination appeared to be stimulated by the increase in dryness at -3 bars. At -6 bars its per cent germination dropped considerably and its recovery was poor having a per cent total germination of only 30 per cent.

## Conclusions

If a species is to become a colonizer of disturbed areas it must first have a nearby seed source or good dispersal mechanism or both, and second, be able to germinate in the provided habitat. Although many of the important tundra species do provide a large and nearby seed source, the results of the germination experiments suggest that they are not able to satisfy the second criterion. In contrast, species commonly important in disturbed areas are not of great importance in the native tundra. However, they do provide a seed source which is both viable and will germinate under a wide range of environmental conditions. It would seem that these later species are ecological opportunists; not really well adapted to the closed tundra situation but having the ability to survive by producing viable seeds until some type of disturbance provides a suitable habitat.

The maintenance in natural communities of small but well adapted populations of colonizing species is one of nature's ways of repairing ecological damage. It would seem reasonable then, that the most ecologically suitable solution to the accelerated disturbances created by man would be to utilize the ecosystem's own repair system, i.e., colonizing species, in any attempts at accelerated revegetation.

## SEEDLING ESTABLISHMENT AND DEVELOPMENT

Preliminary studies suggest that, during the first year, *Arctagrostis latifolia* establishes at much lower rate than many of the agronomic species. *Arctagrostis* overwinters well and by the end of the second year is well established and sending out creeping rhizomes with as many as 5 to 7 shoots per plant.

In seedling studies to date, *Calamagrostis canadensis* has given poor results. In species trials in the field, few seedlings have become established and fewer still have reached maturity. Growth chamber studies have shown that its root growth rate is about half that of *Arctagrostis*. This is surprising in view of its importance in disturbed areas. Root and rhizome studies have shown, however, that once established, a single *Calamagrostis canadensis* plant puts out long rhizomes in several directions producing shoots in great numbers. *Arctagrostis* rhizomes, though producing a great number of shoots, are not as spreading and tend to expand slowly in an ever widening circle. This produces a dense bunch-like appearance in comparison to *Calamagrostis* which is more mat-like. Thus for *Calamagrostis* to become an important species in a disturbed site may require the establishment of a relatively small number of seedlings.

## PLANT GROWTH IN COLD SOILS

In the Low Arctic probably no other factor exerts such a controlling influence both directly and indirectly on the growth and development of plant species as does the presence of permafrost. The continuous permafrost zone today extends north of latitude 67° which approximates the southern boundary of tundra vegetation (Mackay, 1972). The present climate in the Low Arctic is cool enough that, in conjunction with an insulating layer of vegetation and an organic mat, the permafrost is maintained and in many places continues to grow (Mackay, et al., 1972). However, during the summer months the air temperatures on the Tuktoyaktuk Peninsula are surprisingly warm with daily means and mean maxima in July being 10°C and 15°C respectively, and in August 9°C and 12°C respectively (Atmospheric Environment Service, 1972). In the vegetation boundary layer within 15 cm of the soil surface, air temperatures are even warmer; daily means and mean maxima in July being 13°C and 20°C respectively, and in August 10°C and 16°C (1972 field data). Although this relatively warm growing season is short in comparison to temperate regions (8 - 10 weeks in the Low Arctic compared to 14 - 16 weeks in the Edmonton area) this is partially compensated for by a daylight period which is almost continuous throughout the growing season.

It is in the cool and shallow active layer lying just above permanently frozen soil that the growing season environment is the most severe for plant species living in the Tuktoyaktuk Peninsula. Over 80 per cent of the plant's total biomass resides in the zone in the form of roots and rhizomes (Dennis, 1970) functioning both in food storage and in water and nutrient uptake. How cold soils affect plant growth is not completely understood. It is believed to directly affect plants in terms of water and mineral uptake (Kramer, 1940; Zhurbitsky and Shtransberg, 1958) and in mineral incorporation (Dadykin, 1958; Korovin, *et al.* 1963) and indirectly by limiting the rate of microbial release of nutrients to the soil (Russell, 1940).

Obviously plants living in permafrost regions have adapted in some way to growth in cold soils. How this is accomplished is not clear; it may be related to the evolution of enzyme systems capable of efficiently extracting nutrients at low temperatures or it may be a more efficient utilization of available and incorporated nutrients (Savile, 1972). Chapin (1972) from his studies of phosphorus uptake by *Eriophorum vaginatum* presents evidence which suggests that it is not so much a more efficient nutrient utilization as it is an ability to produce large amounts of nutrient-absorbing root biomass at low temperatures. Whatever the method, it would seem that this ability could

be assessed in a comparative manner by investigating the responses of plants in terms of shoot and root growth when grown in cold soils. The objectives of the present experiments were to compare the responses of two arctic grasses and selected introduced grasses when grown in cold soils in terms of: 1) their total shoot and root production, and 2) the amount of root penetration into progressively colder soils.

## Methods

Forty-four 15 cm plastic pots were filled with 1250 g of 3:2:1 100 mineral, peat, and sand greenhouse mixture. Twenty pots of each were seeded with *Calamagrostis canadensis* and *Arctagrostis latifolia* and two each with *Festuca rubra* (arctared fescue) and *Dactylis glomerata* (Kall orchard grass). In each pot approximately 8 seeds were sprinkled in five predetermined locations. The pots were watered, covered with polyethylene bags to impede evaporation and placed in a growth chamber at 20°C and continuous light where the seeds were allowed to germinate. After germination the pots were thinned to five seedlings.

A one-week period was given for the seedlings to become established and then the soils were brought up to field capacity. Field capacity was achieved by soaking the pots overnight and then allowing them to drain for 24 hours. At this point the bottoms were sealed and the pots weighed. Throughout the experiment they were regularly weighed and watered to bring them up to the original weight. A 20:20:20 mixture of N P and K was added to the watering solution at every 6th watering to ensure that nutrients were never in limited supply. The pots were then placed in a growth chamber with continuous lighting, an air temperature of 15°C and a relative humidity of 45 per cent.

Half of the pots of each species were controls and were placed directly in the growth chamber where their soils were allowed to warm to air temperature. The other half were placed in the same growth chamber but on a specially designed soil chilling device which came to be known as a permafrost simulator. Essentially this device was an insulated rectangular drum containing refrigerator coils and filled with ethylene glycol. A thermostat control allowed the selection of the desired solution temperature. The pots were placed directly on the drum. A styrofoam lid with holes cut for each pot was then fitted around the pots. This exposed the surface of the pots and the plants to air temperatures but insulated the rest of the pot so that a gradient of soil temperature from the cold drum to the air surface could be established.

Soil temperature measurements taken in 1971 on the Tuktoyaktuk Peninsula provided an accurate basis for temperature simulation during this experiment. An average soil temperature gradient in July on an undisturbed hummock was 7-9°C at -10cm, 4-5°C at -20 cm and 1.5-2°C at -30 cm. The gradient established in the laboratory in 13 cm of soil was 8.5°C ± 1 at -2.5 cm, 5°C ± 1 at -6.5 cm and 2°C ± 1 at -10 cm. The gradient was much steeper than found under natural conditions but was necessary, to compress a 30 cm active layer into a 13 cm pot. Thermistors were placed in several of the pots and monitored regularly to determine that the temperature gradient was maintained within the allotted limits.

At intervals of four and eight weeks, five control and cold treated pots each of Arctagrostis latifolia and Calamagrostis canadensis were removed, plant heights measured and then placed in a freezer at -40°C for later analyses. The remaining species were removed and treated similarily at the end of the eight-week period.

Upon removal from the freezer, each shoot was clipped, dried at 80°C and weighed. The pots were marked off in terms of the temperature zones existing in the cold soils; 0 to -4.5 cm = 12-8°C, -4.5 to -8.5 cm = 8° -5°C and -8.5 to -13 cm = 5-2°C. The pots while still in a frozen state were cut into these three sections using a band saw. Each section was allowed to thaw and then rinsed using a fine mesh screen to trap the roots which were then dried at 80°C and weighed.

## Results

For ease of discussion, the results will be divided into two subgroups: 1) a comparison of species performance under the control treatments to establish and compare "norms" of performance, and 2) a comparison of treatment effects on root and shoot production both within and between species. The latter comparisons will generally be expressed as per cent reduction in productivity in comparison to the controls.

### Controls

In terms of grams of dry weight production, seedlings of Calamagrostis were smaller than those of Arctagrostis at the four-week harvest, but by the eight-week harvest both species showed the same amount of above ground production (Table 5). Below ground production was only sampled at the eight-week period but showed that root production of Arctagrostis was nearly twice that of Calamagrostis. Both species had similar root distribution within the pots; 40 - 50 per cent lying in the top 4 cm, 25 per cent in the middle 4 cm and 25 - 30 per cent in the bottom 4 cm. Of the total production, nearly 54 per cent was in roots for Arctagrostis and

| Species | Shoot, 4 weeks, n=20, $\bar{X}$ ht. (cm) | Shoot, 4 weeks, n=20, $\bar{X}$ wt. (mg) | Shoot, 4 weeks, n=4, $\bar{X}$ wt. (mg) | Shoot, 8 weeks, n=25, $\bar{X}$ ht. (cm) | Shoot, 8 weeks, n=25, $\bar{X}$wt. (mg) | Shoot, 8 weeks, n=5, $\bar{X}$wt. (g) | *Root wts. 8 weeks (in g., n=5) Upper (12-8°C) | Middle (8-5°C) | Bottom (5-2°) | Total Wt. |
|---|---|---|---|---|---|---|---|---|---|---|
| Calamagrostis canadensis | | | | | | | | | | |
| Control (15°C) | 15.8±1 | 20.6±2 | 103.1±13 | 25.8±.6 | 350±20 | 1.76±.1 | .45±.04 | .25±.07 | .37±.06 | 1.07±.09 |
| Cold Soil Gradient | 12.6±.8 | 9.4±0 | 47.3±6 | 19.7±.6 | 180±10 | .93±.1 | .33±.04 | .02±.01 | .005±0 | .37±.05 |
| Arctagrostis latifolia | | | | | | | | | | |
| Control (15°C) | 22.2±1 | 34.6±3 | 170.3±20 | 38.2±1 | 350±20 | 1.76±.1 | 1.03±.22 | .45±.08 | .53±.07 | 1.99±.36 |
| Cold Soil Gradient | 17.9±1 | 22.1±2 | 109.4±15 | 30.4±1 | 250±20 | 1.25±.1 | .90±.11 | .19±.04 | .07±.02 | 1.15±.15 |
| **Festuca rubra (Arctared) | | | | | | | | | | |
| Control (15°C) | - | - | - | 36.4±1 | 520±44 | 2.60 | .78 | .46 | .65 | 1.89 |
| Cold Soil Gradient | - | - | - | 20.6±1.5 | 105±33 | .49 | .23 | 0 | 0 | .23 |
| **Dactylis glomerata (Kall) | | | | | | | | | | |
| Control (15°C) | - | - | - | 41.2±2 | 774±43 | 3.87 | .82 | .35 | 1.41 | 2.59 |
| Cold Soil Gradient | - | - | - | 30.2±1.5 | 127±22 | .63 | .22 | .01 | 0 | .23 |

Table 5. A comparison of mean ± SE shoot (ht. and wt.) and root (wt.) development of species grown at 15°C air temperature and variable soil temperature (controls 15°C vs. treated 12-2°C)

only 38 per cent for *Calamagrostis*.

Both introduced species, *Festuca rubra* and *Dactylis glomerata*, had large shoot productions, nearly 1.6 to 2 times that of the two natives. Their root production was larger than that of *Calamagrostis* but similar to that of *Arctagrostis*. The distribution of root production for *Festuca rubra* was similar to that of the two native species, however that of *Dactylis glomerata* contained only 30 per cent in the top 4 cm and over half in the bottom 4 cm.

## Treatment Effects

At the four-week sampling, shoots of *Calamagrostis* grown on cold soils showed a reduction of 55 per cent under controls while those of *Arctagrostis* showed only a reduction of 37 per cent with *Arctagrostis* shoots being about twice as productive as those of *Calamagrostis*. By the eight-week harvest, shoots of *Calamagrostis* showed a reduction of 50 per cent while those of *Arctagrostis* were reduced by only 29 per cent. Root production was even more greatly reduced, being 65 per cent less for *Calamagrostis* and 43 per cent less for *Arctagrostis*. When examined according to temperature zones, *Calamagrostis* had a reduction of 27 per cent in the upper ($12^{o}$-$8^{o}$C) zone compared to 13 per cent for *Arctagrostis*. In the middle zone (8-$5^{o}$C) *Calamagrostis* was reduced approximately 90 per cent and was essentially absent in the lower (5-$2^{o}$C) zone while *Arctagrostis* was only reduced 60 per cent in the middle zone and 87 per cent in the lower zone. For both species approximately 80 per cent of the total root production in cold soils is in the 12-$8^{o}$C zone, however, while Calamagrostis has less than 1 per cent of its root mass in the lower 5-$2^{o}$C zone, *Arctagrostis* has over 6 per cent. For both of the introduced species *Festuca rubra* and *Dactylis glomerata* above and below ground productivity was drastically reduced, total shoot and root production at the eight-week harvest being less than 20 per cent of the controls.

## Discussion

The rate of establishment is an important feature in the life history of any species but it is particularly so of species living in climates where the period for establishment is short, as in the Arctic. Because their seeds are of nearly equal weight, both of the native grasses begin their growth with approximately the same food reserves; therefore any differences are attributed to basic differences in genetic makeup. At the four-week period, shoots of *Arctagrostis* of both treated and control pots are 1.7 to 2 times larger respectively than those of *Calamagrostis*. While there was no difference between the control plants at the

eight-week period, shoots of Arctagrostis plants grown on cold soils are approximately 1.4 times larger than those of Calamagrostis.

Studies by Klebesadel in Alaska (1969) have shown that greenhouse-grown seedlings of Arctagrostis latifolia var. arundinacea (Trin.) Griseb. are inferior to several introduced grasses in terms of rate of establishment and production. These were similar to my findings for A. latifolia var. latifolia in species trials in the field. However, controlled environment studies of A. latifolia var. latifolia on the U. of A. campus show that at the four-week period the average shoot weighs 34 mg for controls and 22 mg for those grown on cold soils compared to those of Klebesadel grown under greenhouse conditions which weighed .9 mg. Even given major unaccounted-for differences in treatment, it is hard to conceive changes of that magnitude, suggesting that there are some real genetic differences between the two varieties. Klebesadel's findings also showed that, like A. latifolia var. latifolia, A. latifolia var. arundinacea overwintered well and became highly productive by the second year.

## Adaptations to Cold Soils

The partitioning of productivity between shoots and roots is an expression of the adaptive strategy of a species to a particular environment. In tundra areas root reserves are acknowledged as important means of initiating rapid growth during the spring (Mooney and Billings, 1960), and studies have suggested that a trend exists whereby as one goes further north more of the total plant is underground (Dennis, 1970). In addition, it is advantageous to a species growing in cold soils to produce a root system which can extend into colder soil zones, absorbing nutrients and moisture made available adjacent to the retreating permafrost. In this regard Arctagrostis appears to be the better adapted of the two native species tested. Of its total production at the eight-week period either in cold or warm soils, 50-55 per cent is alloted to the root system. For Calamagrostis only 30-35 per cent of the total production is in the root system, suggesting a slightly different priority in the use of photosynthate. On a weight basis Arctagrostis produces a root system which is 2 to 3 times larger than that of Calamagrostis, although Calamagrostis, having a much finer root system, may have as much or more of an absorbing surface area than Arctagrostis. The total production of Arctagrostis is less affected by cold soils, root production being reduced only 45 per cent and shoot production by 30 per cent as compared to 65 per cent and 50 per cent respectively for Calamagrostis. Though its root production was increasingly reduced with penetration into colder soils, Arctagrostis

demonstrated a greater tolerance to colder zones than *Calamagrostis*. In the upper (12-8$^{\circ}$C) zone, root production for *Arctagrostis* was only reduced 13 per cent compared to 27 per cent for *Calamagrostis*. In the coldest zone (5-2$^{\circ}$C), *Calamagrostis* was essentially absent having only 5 mg of production. *Arctagrostis*, while low, had 14 times that amount or 70 mg of production. This, coupled with the observation that when grown on warm nutrient-rich soils both species produce equal above-ground production, suggests that one of the chief advantages *Arctagrostis* has is the ability to explore and extract nutrients from progressively colder zones.

### Introduced Species

In the control pots, shoots of the introduced species creeping red fescue and orchard grass are 48 and 120 per cent larger respectively than shoots of either *Arctagrostis* or *Calamagrostis*. Their root systems, though nearly twice the size of those of *Calamagrostis* are approximately the same size as those of *Arctagrostis*. When grown in cold soils, however, the production of these two species is greatly reduced, their above-ground production is only about half and their root production 1/15 of that of *Arctagrostis*. Because this was preliminary research and there was no replication in this part of the experiment, any conclusions are highly tenuous.

## MICROENVIRONMENT

During the past summer, data were also gathered on differences in microenvironment between disturbed and adjacent undisturbed areas. These data are still being analyzed but certain general statements can be made. Snow tends to accumulate in disturbed areas. This has the detrimental effect of shortening the growing season by about a week but the beneficial effect of providing winter insulation for seedlings and a flush of moisture which may aid seed germination. As the season progresses, the soils warm. Those in disturbed areas are generally 2 to 3$^{\circ}$C warmer than those on undisturbed hummocks and 4 to 8$^{\circ}$C warmer than those on undisturbed hollows. The active layer in disturbed areas is 10 to 20 cm greater than on undisturbed hummocks and 20 to 30 cm greater than on undisturbed hollows. It was found that when all of the green vegetation was clipped from previously undisturbed hummocks but the peat was left in place the underlying permafrost did not melt out any faster than that under undisturbed vegetation. This suggests that the vegetation is not as important as the peat layer in

insulating the underlying permafrost. Soil moisture, bulk density and soil nutrient samples have yet to be analyzed.

It is hoped that a complete analysis of environmental factors in conjunction with plant productivity and phenology will lead to a better understanding of the biology of native plant colonizers.

## CONCLUSIONS

Certain general and tentative conclusions can be made concerning the present research.

1) The two important colonizing species, Arctagrostis latifolia and Calamagrostis canadensis, are unimportant in the undisturbed tundra but provide a relatively large and viable seed source which has the ability to germinate under a range of moisture and temperature conditions.

2) The important native species tested, Betula nana, Eriophorum vaginatum, and Carex bigelowii, though providing large seed sources, were either low in viability or did not germinate easily.

3) Arctagrostis latifolia establishes slowly the first year but overwinters well, growing rapidly the second year, sending out creeping rhizomes with as many as 5 to 7 shoots per plant.

4) Mature plants of both Arctagrostis and Calamagrostis send out creeping rhizomes which aid in the rapid colonization of disturbed areas.

5) Arctagrostis is better adapted to growing in cold nutrient rich soils than Calamagrostis, producing larger shoot systems, and root systems which are both larger and penetrate deeper into cold soils.

6) The microenvironment in the 1965 seismic lines differs from that of the adjacent tundra in several ways:

a) snow accumulates more and remains longer in the seismic lines

b) the surface of the seismic lines is 45 to 65 cm below the surface of the adjacent tundra

c) soil temperatures in the top 10 cm of the seismic lines are 2 to 3$^{o}$C warmer than in undisturbed hummocks and 4 to 8$^{o}$C warmer than in hollows

d) the active layer in the seismic lines is 10 to 20 cm greater than on undisturbed hummocks and 20 to 30 cm greater than on hollows

e) the peat layer in the undisturbed tundra is more important in preventing permafrost meltout than the vegetation.

## IMPLICATIONS AND RECOMMENDATIONS

A species does not respond to only one or even several factors when adapting to a particular environment. Its continued existence is the result of its integration of a complexity of factors which vary not only according to their relationship to one another but also in time and in space. Because of this, single factor reasoning can be very misleading when selecting species for a particular region. Each factor by itself gives only a clue to the overall suitability of a species and, though some may be more indicative than others, none by itself can provide an accurate gauge for acceptance or rejection. Probably the best indication of adaptability is the continued existence of an introduced species in a particular area over a number of years. Creeping red fescue has already shown its adaptability in revegetation trials at Tuktoyaktuk, and *Calamagrostis* is certainly as important in disturbed areas as the apparently better adapted *Arctagrostis*. The data presented do suggest, however, that under extremes of temperature and moisture stress, genetic potentials of species are tested and accentuated enabling comparisons to be made between species. Of the species tested, *Arctagrostis* is the only truly arctic species having a range fairly restricted to northern areas. Its seed production, germination and root growth in cold soils suggest its greater adaptation to the northern environment. The remainder are less restricted and apparently somewhat less specifically adapted, though able under disturbed conditions to take advantage of an ameliorated environment. All things considered, it would seem that all (with the exception of *Dactlylis glomerata*, which did not overwinter) would be useful in revegetation work. However, the inclusion of *Arctagrostis* and/or *Calamagrostis* into any revegetation program would seem prudent since it appears that they not only have a genetic potential for growth under normal arctic conditions but are also highly enough adapted to withstand extremes of conditions which might eliminate the others.

## NEEDS FOR FURTHER STUDY

If the native grasses discussed in this report are to be utilized in any revegetation program, it must be determined if they can be raised in lower latitudes where the farm land and machinery is available to produce the large quantities of seed needed. Calamagrostis should flower in the boreal region but Arctagrostis may have a longer day length requirement. It would be desirable to raise the seed in as close a latitude as possible to that where it would be utilized, enabling natural selection to eliminate less hardy but recurrent genotypes.

If it can be shown that this species can be raised successfully at lower latitudes, then seed collections should be made at various latitudes along the pipeline route and grown in a common garden. Here ecotypes could be identified, tested and selected to meet the needs of any revegetation program.

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## SUMMARY

Two arctic grasses, Arctagrostis latifolia var. latifolia and Calamagrostis canadensis subsp. canadensis, observed to be naturally recolonizing disturbed areas on the Tuktoyaktuk Peninsula, were studied to determine their potential for use in an accelerated revegetation program. Calamagrostis canadensis, a species with a wide north-south range, was found to have a generally broad ecological amplitude in tundra environments, being found on moist to dry sites with either shallowly or deeply-thawed active layers. Its lack of vigour, however, was suggested by an inability to produce many flowering heads. Arctagrostis latifolia is a more truly arctic species, being circumpolar and restricted to above 55°N latitude. It is also

found in a range of northern environments but appears to favour more moist conditions with an active layer of over 35 cm by the end of the growing season. It appears vigorous in all areas of occurrence, producing numerous seed heads.

One of the factors important in the successful colonization of disturbed areas by these species is the production of viable seed which germinates under a range of environmental conditions. Species important in the undisturbed tundra, such as Betula nana, Carex bigelowii and Eriophorum vaginatum, produce large amounts of seed, most of which are either non-viable or difficult to germinate. Arctagrostis and Calamagrostis produce relatively small amounts of seed. However, what is produced has germination percentages over 80 per cent and rates of germination which are relatively rapid over a range of temperature and moisture conditions.

Seedling establishment of these two species is slow the first year. They overwinter well and by the second season produce numerous flowering shoots. Laboratory studies of shoot and root responses to cold soils suggest that, of the two species, Arctagrostis is the better adapted to the permafrost environment. At the end of an eight-week growth period in cold soils, Calamagrostis showed reductions of 50 per cent for shoots and 65 per cent for roots vs. controls compared with 29 per cent and 43 per cent respectively for shoots and roots of Arctagrostis. Penetration of root systems into progressively colder soils was also reduced for Calamagrostis, its growth being limited at the 5-8$^{\circ}$C zone, while Arctagrostis roots penetrated into the 2-5$^{\circ}$C zone. Both of these species were superior to the two agronomic species tested, Festuca rubra and Dactylis glomerata, both of which showed dramatic reductions in shoot and root production when grown in cold soils.

Studies of microenvironmental differences between disturbed and undisturbed tundra established that snow depths are greater and snow lies for longer periods in disturbed areas. This may function to provide both winter protection for seedlings and provide greater surface moisture for seed germination. Disturbance also changes the surface energy budget, allowing soils to warm more and to thaw more deeply. Soils in disturbed areas generally melt out 10-20 cm more and are 2-3$^{\circ}$C warmer in the upper 10 cm than on undisturbed hummocks and melt out 20-30 cm more and are 4-8$^{\circ}$C warmer in the upper 10 cm than on undisturbed hollows. The warming of the soil has a positive affect on both microbial and plant root activity and the increase in active layer provides a greatly increased volume of soil for root exploration. The combination of these factors may act, if not to produce an absolute increase in soil nutrients, at least to provide a greater available nutrient medium for those plants which are adapted to quickly establish and expand a root system into disturbed soils.

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# REVEGETATION STUDIES - NORMAN WELLS, INUVIK AND TUKTOYAKTUK, N.W.T. AND PRUDHOE BAY, ALASKA.

by

Helios Hernandez

## INTRODUCTION

The discovery of oil and gas at Prudhoe Bay, Alaska in 1968 and subsequent similar discoveries in the geologically-related sedimentary basins of the northwestern Canadian Arctic may result in a proposal to construct a gas pipeline along the Mackenzie River Valley. This pipeline, because of its great length, would pass through a variety of broad regions, each with its own unique and interrelated characteristics of geology and physiography, soils, climate, animal life and vegetation. The construction of such a structure would of necessity, result in disruption of the surface plant cover and alter the present soil energy balance. In ice-rich permafrost areas such alterations could result in ice melt, and thus affect soil stability, and lead to engineering and construction difficulties. Because of these possible problems, investigations have been carried out to develop construction and engineering techniques which will minimize the impact on the surficial plant cover. Vegetation is important not only in maintaining the thermal regime and stability of the soil but it provides the habitat for most northern animals. Thus, changes in the vegetation will affect these animals.

Reseeding and agronomic research in northern regions was pioneered by Government agricultural research stations such as those at Palmer, Alaska and Beaverlodge, Alberta. Agronomic and native species have been tested and varieties selected for winter hardiness, seed production and herbage yield (e.g. Elliott 1971- in Canada; Klebesadel and Laughlin 1964, Klebesadel *et al*. 1964, Klebesadel 1965 - in Alaska).

Several reseeding studies have recently been established in relation to the various proposed oil or gas pipelines through parts of Canada, Alaska, or both. Alaskan species and fertilizer trials include those of McGrogan *et al*. (1971) for ARCO Chemical Company on the North Slope, and Van Cleve and Manthei (1971) for the Alyeska Pipeline Service Company. Bolstad (1971) reports on a study established by the Bureau of Land Management to examine the reseeding of fire guard lines (catlines) in interior Alaska. Canadian investigations include those reported by Wein (1971a), Younkin (1972) and Williams Brothers Canada Ltd. (1972) in relation to the proposed gas pipeline and other disturbances along the Mackenzie River valley and Delta regions.

The present study involved the continued sampling and monitoring of experimental plots previously established by (a) Walter E. Younkin of the Department of Botany, University of Alberta for ALUR (Arctic Land Use Research Program of the Department of Indian Affairs and Northern Development) and the APOA (Arctic Petroleum Operators' Association) in 1970 and 1971 and by (b) Dr. Ross W. Wein, then also of the Department of Botany, University of Alberta, for the EPB (Environment Protection Board, sponsored by Gas Arctic Systems Study Group) in 1971. The current project also involved the establishment of new experimental plots in 1972.

Specific questions and studies discussed in this report are described below:

(a) Sampling of previously established plots provided information on the ability of the different species tested to survive 1 or 2 winters and 2 or 3 summers in the study areas.

(b) The most favourable time(s) of the year for seeding could be determined from date of seeding studies.

(c) Nurse crop competition studies provided information on the feasibility of using quick-growing cereal annuals to increase perennial establishment and production or, at least, not to markedly impair them while providing good first year cover.

(d) The newly-established study on a winter road, using species mixes, should allow comparison of the suitabilities of native and agronomic species as potential revegetators.

(e) The ability of already-sown agronomic species to produce viable seed in the north could be determined from germination tests.

(f) The ability of these same species to invade, survive and establish successfully in native undisturbed plant communities was monitored.

(g) The rate and success of the invasion of weedy species into northern areas could be estimated from plants collected around inhabited areas.

In general, the purpose of these studies has been to obtain information on the possibility of re-establishing plant cover on disturbed areas in the north. With this information and the knowledge of the rates of natural recolonization of disturbed areas, future decisions on the feasibility and need for reseeding may be made. Combining

these results with those of vegetation and soil surveys, geological mapping, terrain investigations and wildlife studies, an assessment of the possible impact of a project of the magnitude of the proposed pipeline may be made.

## DESCRIPTION OF STUDY AREAS

Studies on the re-establishment of vegetation on disturbed areas must be, by their nature, in localized sites. The four sites used in the current study (Fig. 1) are located near Norman Wells, N.W.T. (65°17'N, 126°41'W) on the Mackenzie River; Inuvik, N.W.T. (68 20'N, 133 40'W) on the East Channel of the Mackenzie Delta; Tuktoyaktuk, N.W.T. (69°25'N, 132°57'W) by the Arctic Ocean, northeast of the mouth of the Mackenzie Delta and Prudhoe Bay, Alaska (70°15'N, 148°30'W) near the Arctic Ocean west of the delta of the Sagavanirktok River. Each site is in a region of different geology, climate, soils, vegetation and wildlife along the northern portion of the proposed gas pipeline.

The subject of this report is an evaluation of the possibility and means of revegetating disturbed areas. However, each of the above listed characteristics impinges directly or indirectly on this project by defining a unique region in which the response of seeded species may differ from area to area. Thus, this section is a brief review of the major characteristics of these northern regions.

### Surficial Geology, Physiography and Glacial History

Studies of geology, physiography, and glacial history in the areas of the Mackenzie River Valley and Delta and in the Arctic Coastal Plain of the northern Yukon and Tuktoyaktuk Peninsula have accelerated in recent years (Hughes 1972b). Mackay (1963) summarizes the knowledge of the Mackenzie Delta area up to that time and Fyles (1966, 1967) discusses its glacial history. Rampton (1971) relates his classification of the surficial deposits of the area to Mackay's (1963) physiographic regions. Hughes and Hodgson (1972) and Hughes (1972a) have examined the Quaternary geology and mapped the surficial geology of the northern Yukon and northwestern District of Mackenzie. Ritchie and Hare (1971) discussed the climate and Quaternary vegetation of this area. Brief summaries of current projects in mapping the various surficial landforms, geology and glacial history of the vast area of the Mackenzie corridor are given in Geological Survey of Canada (1973). Terrain and coastal conditions on the Alaskan Coastal Plain are discussed by Sellmann *et al.* (1972).


Figure 1 Map showing location of study sites.

Detailed studies of the surface and near-surface geology of the pipeline route itself have been undertaken as part of the engineering studies prior to construction (see Mollard 1972 for methods). Further and much more detailed discussions of the terrain, hydrology and other aspects in relation to the pipeline are currently being assembled (L. Hurwitz, Templeton Engineering Co., Winnipeg; personal communication).

Permafrost and Ice Characteristics

Permafrost is defined as ground continually at or below $0^{o}$ ($32^{o}$F) irrespective of the water content of the material. The three northern most sites, Prudhoe Bay, Tuktoyaktuk and Inuvik are in the zone of continuous permafrost. Norman Wells is in the northern portion of the zone of discontinuous permafrost (Brown 1967).

One of the characteristics of permafrost regions is that water content of the soil is usually high and, under certain conditions, ice bodies develop. Ice lenses may be massive; but less common than the much less-massive ice wedges. The ice content of such bodies (weight of ice to dry soil) is generally 100 to 1000 per cent, usually in the upper range (Mackay 1966, 1971). Both types are commonly, but not exclusively, found in fine-grained sediments. The origin of massive icy beds in permafrost is described by Mackay (1971). Rampton and Mackay (1971) describe their distribution in the Richards Island-Tuktoyaktuk Peninsula region. The broad distribution along portions of the proposed pipeline is discussed by Mackay (1972) in relation to the history of these areas.

Once the insulating vegetative cover is disturbed in permafrost areas, thawing increases downwards. Subsurface ice may be exposed and melt. Hernandez (1972) found that pushing aside of the thawed surface layer and exposure of mineral soil during a seismic operation in the summer of 1965 in the Tuktoyaktuk Peninsula resulted in an average subsidence of 25 to 30 cm. Since 1966, seismic operations in these areas have generally been in winter. Removal of surface peat and plant cover has been much less, as have the resulting thaw and subsidence. Kerfoot (1972) is currently investigating the long term effects of exploration activity on terrain and permafrost.

Climate

Long term climatic data from meteorological stations in the towns near the three Canadian study sites and from the two closest meteorological stations to Prudhoe Bay, Alaska (Barter Island and Barrow) are summarized in Table 1. The influence of the Arctic Ocean moderates the climate most

TABLE 1 PRECIPITATION AND TEMPERATURE NORMALS FOR THE WEATHER STATIONS AT NORMAN WELLS, INUVIK AND TUKTOYAKTUK, N.W.T., AND BARTER ISLAND AND BARROW, ALASKA, THE TWO STATIONS NEAREST PRUDHOE BAY (70°15'N; 148°30'W)

| | LOCATION, ALTITUDE[a] OF STATION AND LENGTH OF RECORD | | | | |
|---|---|---|---|---|---|
| | Norman Wells[b] 65°17'N 126°48'W 209 ft. 27 yrs. | Inuvik[b] 68°18'N 133°29'W 200 ft. 13 yrs. | Tuktoyaktuk[b] 69°27'N 133°00'W 60 ft. 13 yrs. | Barter Island[c] 70°08'N 143°38'W 39 ft. 23 yrs. | Barrow[c] 71°18'N 156°47'W 31 ft. 51 yrs. |
| Mean Total Precipitation cm | 33.45 | 26.04 | 12.95 | 15.95 | 10.82 |
| Mean Total Rainfall | 19.53 | 10.13 | 7.34 | f | f |
| Mean June Precipitation | 3.66 | 1.30 | 1.35 | 1.30 | 0.91 |
| Mean July Precipitation | 5.61 | 3.43 | 2.21 | 2.23 | 1.96 |
| Mean August Precipitation | 6.17 | 4.62 | 2.88 | 2.67 | 2.29 |
| Mean Total Summer Snowfall[d] | 0.76 | 6.86 | 4.06 | 8.89 | 4.57 |
| Mean Total Snowfall | 143.2 | 174.0 | 55.6 | 118.6 | 72.6 |
| Mean October Snowfall | 23.1 | 34.5 | 11.9 | 24.4 | 17.5 |
| Mean Daily Temperature °C | -6.3 | -9.7 | -10.7 | -12.0 | -12.4 |
| Mean Daily Maximum | -1.4 | -4.6 | -7.2 | -8.7 | -9.4 |
| Mean Daily Minimum | -11.2 | -14.9 | -14.2 | -15.3 | -15.5 |
| Mean July Temperature | 16.1 | 13.3 | 10.3 | 5.3 | 3.9 |
| Mean August Temperature | 13.2 | 10.3 | 8.7 | 4.4 | 2.9 |
| Mean January Temperature | -28.7 | -29.3 | -27.2 | -27.1 | -26.8 |
| Mean February Temperature | -26.6 | -29.4 | -29.2 | -28.7 | -27.9 |
| Maximum Recorded Temperature | 32.8 | 31.7 | 30.0 | 23.9 | 25.6 |
| Minimum Recorded Temperature | -54.4 | -56.7 | -50.0 | -50.6 | -48.9 |
| Number of Days with Frost[e] | 239 | 269 | 277 | 312 | 324 |

[a] Altitude in feet above mean sea level

[b] Data from Atmospheric Environment Service 1972 (1941 to 1970 Normals)

[c] Data from Environmental Data Service 1972 (1931 to 1960 Normals)

[d] Summer: June, July and August

[e] A day with frost is one in which the minimum temperature is 32°F or lower

[f] Data not given

noticeably at Prudhoe Bay, to a great extent in summer and less strongly in winter. Temperatures there are no colder in winter, if not slightly warmer, than at the Canadian sites despite its more northerly location. The mass of relatively warm water below the ice serves partly to overcome the longer period of little or no incoming solar radiation at this site (Thompson 1967). July, the warmest month at all sites, is 20°F lower on the average at Prudhoe Bay than at Norman Wells and 10°F lower than at Tuktoyaktuk, despite the possibility of a longer period of continuous insolation at Prudhoe Bay. Coastal fogs, however, are quite frequent during the summer. The ice pack breaks up in late July or early August on the Alaskan coast (Environmental Data Service 1972) but the harbour at Tuktoyaktuk is usually ice free by the third or fourth week in June (Mackay 1963). The Mackenzie River ice usually breaks up in mid-May at Norman Wells and by the end of May at Inuvik (Mackay 1963).

Precipitation is highest at Norman Wells where more than half of the 33 cm falls as rain. Inuvik, because of the heavy snowfall, also has more than 25 cm of total precipitation but only 10 cm of rain. Tuktoyaktuk has a slightly lower rainfall (7.5 cm) and much less snow for a total precipitation of only 13 cm. Data from the coastal Alaskan meteorological stations seem to indicate that Prudhoe Bay is not likely to differ greatly from Tuktoyaktuk with respect to precipitation. Most rainfall at all sites is during July and August when plants are most active.

The number of days with frost (minimum temperature below 0°C) increases greatly from 239 at Norman Wells to probably more than 310 at Prudhoe Bay. The incidence of freezing temperatures during July and August is much greater on the Alaskan coast (approximately 10 days per month-Environmental Data Service 1972) than even at Tuktoyaktuk (1 day per month-Atmospheric Environment Service 1972). Although the attaining of 0°C during one day is not likely to permanently impair plant growth, the above figures do provide some information on potential killing frost during the summer. Thus, in view of both the shorter growing season and the greater possibility of a killing frost it is not surprising that revegetation attempts are more difficult as one goes north.

## Soils

Studies of the soils in areas through which the northern portion of the pipeline may pass have been few until recently. Day and Rice (1964) describe soils from Norman Wells, in the boreal forest; Inuvik, in the tundra to boreal forest transition zone and the Caribou Hills (30 miles north of Inuvik). Janz (1973) is currently investigating the influence

of topography on vegetation and soil patterns of tundra areas from Inuvik to Tuktoyaktuk. Haag (1972) discusses the role of nutrients in limiting production in two natural plant communities near Tuktoyaktuk.

Arctic and subarctic soils, their processes, development and classification, have been more extensively studied in Alaska by Tedrow and his associates (e.g. Tedrow et al. 1958, Tedrow and Cantlon 1958, Tedrow 1966, 1970).

The soils and vegetation along the proposed pipeline routes are currently being investigated (A. Janz, Department of Botany, U. of Alberta personal communication).

Vegetation

Vegetation in a particular area is a product of the local geology, climate, history and soils. Cody (1971) has recently summarized the geographic relationships and origins of the flora of the Yukon and Northwest Territories. Recent floras and other manuals most applicable to the varied vegetation of the forest and tundra along the northern portion of the pipeline route include Wiggins and Thomas (1962), Porsild (1964), Cody (1965) Hultén (1968) and Viereck and Little (1972).

Studies and classification of the great variety of northern tundra and forest plant communities have been few until recently. Britton (1957) summarized the knowledge of the tundra of the arctic slope of Alaska. The upland tundra vegetation of the eastern Mackenzie Delta region has been classified recently (Corns 1972). A vegetation survey in the northern Yukon in relation to the proposed gas pipeline was completed in 1972 (Wein 1971b for preliminary results). Soils, vegetation and landform are currently being investigated in the upper Mackenzie River Valley (Lavkulich 1972) and by the Federal Government (Strang 1972). Johnson & Vogel (1966) describe the vegetation of the Yukon Flats region in Alaska.

The knowledge of the vegetation which exists in an area, as well as of species likely to grow on disturbed areas is of importance to revegetation attempts. Past and current vegetation surveys along the proposed routes of the line provide information on species able to naturally revegetate. These surveys also provide a classification into which can be extra-polated and integrated the results from fixed revegetation study plots.

For the purposes of revegetation, the northern portions of the proposed pipeline routes are divisible into several major and broad soil-vegetation-climate landscape units. These are:

(a) The low-centre polygon/wet-sedge tundra of the Arctic Coastal Plain in Alaska (predominantly the Prudhoe Bay area).

(b) The moist cottongrass tussock tundra from the foothills of the Brooks Range to the Arctic Ocean from the western edge of the Mackenzie Delta to near Prudhoe Bay (Coastal Alternate).

(c) The dwarf shrub-heath hummocky tundra of the Tuktoyaktuk Peninsula, Richards Island and Caribou Hills uplands from Inuvik north.

(d) The tundra to boreal forest transition zone from Inuvik to the vicinity of Fort Good Hope (the northern portion of the main Mackenzie Valley Route and southern half of the Mackenzie Delta Lateral).

(e) The great variety of boreal forest types of the Mackenzie Valley proper, southern N.W.T. and northern Alberta (Main Mackenzie Valley Route) and of the Yukon (Interior Alternate).

Within each of the above broad zones, some of the other units also exist to a greater or lesser extent. For example, alpine cottongrass tussock tundra occurs commonly in the Interior Alternate in the northern Yukon at the higher elevations of the Richardson Mountains, Brooks Range and other plateau and mountain areas.

The site at Prudhoe Bay is in (a). The vegetation and other features of this wet sedge coastal tundra site are briefly described by Wein (1971a) and the general characteristics of the Arctic Coastal Plain are summarized by Britton (1957) and Brown (1970). Tuktoyaktuk is in (c) above. The soil and vegetation characteristics of this area dominated by upland dwarf shrub-heath hummocky tundra (Haag 1972, 1973). Corns (1972) provides information on the distribution of the other tundra types within this area. The area around Inuvik (in (d) above) is predominantly an open 6 m tall black spruce forest with an understory of shrubs and heath vegetation among the moss mat. On southern exposures and coarse textured material, however, paper birch predominates Wein (1971a). The closed black spruce forest around Norman Wells (in (e) above) and the general site characteristics are given by Wein (1971a) and Haag (1973).

## Wildlife

Investigations of the possible impact of a gas pipeline on animals have been and are being carried out. Studies include those of Calef and Lortie (1973) and Renewable Resources Consulting Services Ltd. (1971a) for caribou, Campbell (1973), and Campbell and Davies (1973) for birds, Renewable Resources Consulting Services Ltd. (1971b) for furbearers and Hatfield *et al*. (1972) for fresh water fish.

Bliss and Peterson (1973) have recently summarized the ecological information which has been obtained in relation to the exploration activity in northern Canada.

# EXPERIMENTS AND METHODS

## Plot Locations

The geographical location of the four major study sites (Norman Wells, Inuvik and Tuktoyaktuk, N.W.T., and Prudhoe Bay, Alaska) is given in Fig. 1. The various plot locations in relation to each area and details of the experimental designs are given in Appendix A.* As each experiment is discussed in the subsequent text, reference will be made to the appropriate figures(s) in Appendix A.

Table 2 summarizes the types of experimental plots, their location, the year in which they were established, and the principal investigators who established them.

## Species Nomenclature

All agronomically developed and native species used in these vegetation studies are listed in Table 24 (Appendix), following Hultén's (1968) nomenclature. Species tested in the plots will be referred to by their common name, i.e. native species will be referred to by their scientific and common name, if available.

## Continued Monitoring of Experiments

### Established by W.E. Younkin

Species and fertilizer trials were established and monitored in 1970 and 1971 at Inuvik and Tuktoyaktuk (Younkin 1972).

The 1970 experiments, established in June at Inuvik and in mid-July at Tuktoyaktuk, tested three fertilizers (nitrogen, phosphorus and lime, alone and in combinations) and 16 species of agronomic grasses. These plots were established on two

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*Appendix A is on file and may be consulted on application to Manager, A.L.U.R. Programme, Northern Natural Resources and Environment Branch, Dept. Indian and Northern Affairs.

TABLE 2 LIST OF SITES, EXPERIMENTS, INVESTIGATORS[a] WHO ESTABLISHED THEM AND YEAR ESTABLISHED.

| Site Location | Date of Seeding | Experiment, Investigator, Year Established | | | | | |
|---|---|---|---|---|---|---|---|
| | | Species and/or Fertilizer Trials | | | Nurse Crop | Winter Road | Seedling Survival in Native Vegetation |
| | | On Berm | Soil Type Org[b] | Min[b] | | | |
| Norman Wells 65°17' N 126°41' W | RWW 1971 | RWW 1971 | | | RWW 1971 HH 1972 | HH 1972 | RWW 1971 |
| Inuvik 68°20' N 133°40' W | RWW 1971 | RWW 1971 | WEY 1970 1971 | WEY 1970 1971 | RWW 1971 HH 1972 | | RWW 1971 |
| Tuktoyaktuk 69°25' N 132°57' W | | | WEY 1970 1971 | WEY 1970 1971 | | HH 1972 | |
| Prudhoe Bay 70°15' N 148°30' W | RWW 1971 | RWW 1971 | | | RWW 1971 | | RWW 1971 |

a investigator and source for initial experiments: RWW- R.W. Wein, 1971; WEY- W.E. Younkin, 1972; HH- H. Hernandez - this report.

b Org - Organic Soil; Min - Mineral Soil

soil types, organic and mineral, at each site. (Appendix A Figs. 2 and 3 for Inuvik; Figs. 5 and 6 for Tuktoyaktuk). Sampling in August 1970 consisted of height measurements. The overwintering success of these plots was determined in late May 1971. In August 1971, height and extent of seed head production was measured for the 8 most successful species.

The 1971 experiments consisted of further species and fertilizer trials on both soil types at both sites. The fertilizers used were nitrogen and phosphorus. The species tested included (a) four agronomic species found to be successful in the previous study (Nugget Kentucky bluegrass, Arctared creeping red fescue, Frontier reed canarygrass and Engmo timothy), (b) two new agronomic species (kall orchard-grass and Fairway crested wheatgrass), (c) two native grasses (tall arcticgrass - *Arctagrostic latifolia* and bluejoint - *Calamagrostis canadensis*) found to be successful natural colonizers of disturbed areas (Hernandez, 1972) (Appendix A Figs. 2 and 3 for Inuvik organic soil, Figs. 16 and 17 for Inuvik mineral soil; Figs. 5 and 6 for Tuktoyaktuk plots). All plots were sampled in August 1971 for height and above and below ground productivity.

During the 1972 season all of Younkin's plots were monitored. Overwintering success was determined in late June or early July by a subjective cover rating which took into account both height and ground cover for each species. In August, 9 height measurements were taken for each species in the 1970 plots and 30 for the 1971 plots. One cover rating was estimated for each of the three replicates per treatment. Seed head production was also determined.

Established by Wein

Several different experiments were established in 1971 by Dr. Ross W. Wein at Norman Wells and Inuvik, N.W.T. and Prudhoe Bay, Alaska (Wein 1971a). Each experiment is discussed separately below.

Species trials over berms:

One set of species trials was established at each location in 1971. Those at Norman Wells (Appendix A Figs. 7, 8 and 9) and at Prudhoe Bay (Appendix A Figs. 12 and 14) were over Gas Arctic experimental gas test pipes. The trials at Inuvik (Appendix A Figs. 2 and 4) were over the buried oil loop at the Mackenzie Valley Pipeline Test Facility. Cover and seedling numbers in a 20x50 cm quadrat at five different positions on the berms at Norman Wells and Prudhoe Bay were determined in August 1971. The Inuvik site was not sampled as there was little sign of plant establishment.

Sampling in 1972 consisted of cover and height measurements and estimates of flowering. Prudhoe Bay and Inuvik were sampled once each, in August. Norman Wells was sampled three times during the growing season, early July, early June and late August.

Date of seeding:

Plots were established at each location on different dates throughout the summer of 1971. (Appendix A Figs. 7 and 11 for Norman Wells; Figs. 16 and 18 for Inuvik; 12 and 15 for Prudhoe Bay). Seedling height was measured at each plot in August 1971. In 1972 the plots at Inuvik and Norman Wells were sampled for height and cover rating, both early in the growing season and in late August. The phenological state of each species (seedling, vegetative or flowering) was also noted for each date at the end of the summer. The plots at Prudhoe Bay were sampled only once, in mid-August. Here, height and cover rating were also measured. However, neither the flowering nor the seed set abilities of the various species could be determined at this location because of heavy grazing by caribou throughout the summer.

Nurse crop competition:

This experiment was also established in 1971 at all three sites. (Appendix A Figs. 7 and 10 for Norman Wells, Figs. 16 and 17 for Inuvik; Figs. 12 and 13 for Prudhoe Bay). All plots were heavily grazed in 1971 by small mammals and hares and thus very limited data were obtained. However, there was sufficient growth in 1972 to warrant sampling. Cover for each species, including native species, was determined in three 20x50 cm quadrats per treatment.

Survival of agronomic seed sown in native plant communities:

Four 5x5 m plots in undisturbed plant communities were sown in mid-June 1971 with a mix of 11 agronomic species at each site. (Appendix A Fig. 7 for Norman Wells, Fig. 2 for Inuvik; 12 for Prudhoe Bay). The number of live seedlings in 80 quadrats (20x50 cm) was counted at each site in both 1971 and 1972.

## New Experiments

### Winter Road Revegetation Study

A study to investigate the revegetation of winter roads and related disturbances by using seed mixes of both agronomic and native species was established near Norman Wells and Tuktoyaktuk in 1972. (Appendix A Fig. 19 for Norman Wells; Fig. 20 for Tuktoyaktuk).

A 1971-72 winter seismic line and trails bulldozed through native vegetation were used to simulate the road at Norman Wells. At Tuktoyaktuk, plots were established on the winter road used by Imperial Oil Ltd. to supply and move outlying rigs from its Tuktoyaktuk base camp.

Both heavily disturbed and lightly disturbed areas at each site were seeded with the following mixes:

(a) Native Mix: Bluejoint; tall arcticgrass; marsh fleabane; fireweed.

(b) Agronomic Mix: Arctared creeping red fescue; Canon Canada bluegrass; Kall orchardgrass; Climax timothy.

(c) Total Mix: Mix of all 8 species in (a) and (b) above.

Two levels of fertilizer were used: 0 and 100 kg/ha of each of elemental nitrogen (N) and phosphorus (P). Ammonium nitrate (34-0-0) was the nitrogen source and superphosphate (0-20-0) the source of phosphorus. There were 18 replicates seeded at Norman Wells; 13 at Tuktoyaktuk. Each replicate consisted of six 2x2 m subplots, seeded so that all species in a mix had approximately equal numbers of viable seed, as determined from germination tests. Total sowing intensity was 1000 viable seeds per $m^2$ depending on the species mix.

In late August, all plots were sampled. Cover, density and height were determined for each species wherever possible.

Nurse Crop Competition

New nurse crop competition plots were established at Norman Wells and Inuvik because those of 1971 appeared to have been eliminated by heavy grazing by rodents and hares (Wein, 1971a). Types of seed and rates of application of seed and fertilizer in 1972 were the same as for 1971 (i.e. 100 kg/ha of both elemental N and P fertilizer and 250 seeds/$m^2$ of each species in the mix). The 1972 plots were slightly smaller than those of 1971 (2.0x1.5 m in 1972 vs. 2.5x1.25 m in 1971) (Appendix A Figs. 7 and 10 for Norman Wells; Figs. 16 and 17 for Inuvik). Cover for each species was determined in 3 quadrats (20x50 cm) per treatment in August 1972.

Viability of Seed Produced in Test Plots

Seed was collected from several of the previously established plots at Tuktoyaktuk, Inuvik and Norman Wells. Seed germination percentages were determined for three lots

of 25 seeds for each combination of treatment and species collected. Two sets of germination tests were carried out in continuous light at 20° C in a germination chamber. One was without any pretreatment; the other was prechilled for 10 days at 4° C.

Plant Collections of Inhabited Areas

Voucher specimens of plants were collected around the townsites, dumps and/or airstrips at Norman Wells, Fort Macpherson and Inuvik, N.W.T. and Old Crow, Yukon Territory (See Fig. 1). These are being identified and should provide information on the success and rate of establishment of weedy species into these northern areas. The specimens have been deposited at the Herbarium of the Department of Botany, University of Alberta.

Data Presentation and Analysis

The data have been tabulated as means ± standard error. Some of the experiments have been further analyzed with an Analysis of Variance (Split Plot, Factorial or Randomized Block depending on the experiment) as outlined by Snedecor (1956). Percentage data were transformed using the arc-sine transformation as recommended by Snedecor (1956). A Duncan's (1965) Multiple Range Test was used to examine the statistical significance of the differences between means. Unless otherwise stated, the significance level used was the 95 per cent confidence limit. Where statistical treatment was not done, the performance of the various species tested was compared by ranking.

## RESULTS AND DISCUSSION

The results obtained from each of the previously described experiments (see Experiments and Methods) are presented and discussed in this section, the 1972 data being compared to those of previous years. A broader and more extensive discussion of the major results and their relationships with other studies is presented in the Integration.

Experiments Established by Younkin

1970 Species and Fertilizer Trials

Species and fertilizer trials were established in mid-June 1970 at Inuvik and in mid-July at Tuktoyaktuk on both organic and mineral soils. Height was measured for the species at Inuvik in August of both 1970 and 1971 (Younkin, 1972). Because of the late establishment of the plots at Tuktoyaktuk, plant establishment and growth were poor and so these data were not included.

As the end of the first season, no differences in response were noted between soil types at Inuvik. The fertilizer treatments, P alone and N+P (112kg/ha of each) resulted in taller plants on both soil types than all other treatments,in which growth was approximately equal (Younkin 1972).

By August 1971, plant growth was generally greater on mineral than on organic soil. The fertilizer treatments containing phosphorus (P, N+P, N+P+L) had greater growth than did control, L or N. An analysis of variance of these data has since supported Younkin's (1972) conclusions. The phosphorus treatments had taller plants than the others at the 1 per cent level of significance on a Duncan's (1965) Multiple Range Test.

Because the data were height measurements, differences between species on this basis are largely due to their genetically determined growth form. Such data, thus, are not necessarily indicative of potential for producing extensive ground cover. Younkin (1972) noted that by August 1971, although Engmo timothy, Meadow foxtail, and Slender wheatgrass were the tallest species, they produced little ground cover when compared to Boreal and Arctared creeping red fescue and Canon Canada bluegrass.

The cover rating and height data for the late August 1972 sampling of these fertilizer and species trials are presented in Table 3 for the Inuvik plots and for the three species which still survived at Tuktoyaktuk. Analyses of variance of the cover rating data was carried out for Inuvik and Tuktoyaktuk separately.

At Inuvik, mineral soil had a significantly greater plant cover than organic soil for all species and fertilizers (46 per cent of the row covered vs 22 per cent). No differences could be detected between fertilizer treatments. Success of species, based on cover rating, was variable. Three broad groups were found: (a) extremely poor species with virtually no cover (at most 6 per cent): Sawki Russian wildrye, Greenleaf pubescent wheatgrass, Streambank wheatgrass and Polar bromegrass; (b) species with low mean cover of 20 to 25 per cent: Canon Canada bluegrass and Imperial and Frontier reed canarygrass; and (c) species ranging from good to excellent mean cover over both soil types: Engmo timothy (46 per cent), Slender wheatgrass (60 per cent), Boreal creeping red fescue (65 per cent), Meadow foxtail (74 per cent), Arctared creeping red fescue (79 per cent) and Nugget Kentucky bluegrass (82 per cent).

TABLE 3 MEAN COVER RATING[a] AND HEIGHT[b] OF SPECIES SOWN IN MID-JUNE 1970 AT INUVIK AND IN MID-JULY AT TUKTOYAKTUK, N.W.T. ON ORGANIC AND MINERAL SOIL TREATED WITH DIFFERENT FERTILIZERS. DATA ARE GIVEN AS MEANS ± STANDARD ERRORS FOR 3 HEIGHT MEASUREMENTS AND 1 COVER RATING FOR EACH OF 3 REPLICATES PER TREATMENT. DATA FROM TUKTOYAKTUK ARE PRESENTED ONLY FOR THE 3 SPECIES WHICH SURVIVED IN MORE THAN ONE TREATMENT (SAMPLED AUGUST 19,1972 AT TUKTOYAKTUK, AUGUST 23 AT INUVIK (SPECIES ARE LISTED IN DESCENDING ORDER OF OVERALL MEAN COVER RATING)

| | | | Treatment[c] and Soil Type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Control | | N | | P | | L | | N+P | | N+P+L | |
| | | | Organic | Mineral | Organic | Mineral | Organic | Mineral | Organic | Mineral | Organic | Mineral | Organic | Mineral |
| | | | Cover Rating and Height (cm) | | | | | | | | | | | |
| Nugget Kentucky bluegrass | | C[a] | 5.0±0.0 | 3.3±0.7 | 4.0±0.6 | 3.0±0.6 | 5.0±0.0 | 3.3±0.7 | 4.5±0.5 | 4.7±0.3 | 5.0±0.0 | 4.3±0.3 | 5.0±0.0 | 3.7±0.3 |
| | | H[b] | 15.0±1.5[f] | 13.7±0.9[F] | 15.0±1.0[f] | 12.0±1.8[F] | 21.3±2.2[F] | 47.0±1.1[F] | 14.5±1.3[F] | 61.3±3.7[F] | 21.3±2.2[F] | 55.3±2.7[F] | 19.0±1.6[F] | 58.0±3.7[F] |
| | T | C | 2.5±0.5 | 0.3±0.3 | 3.5±0.5 | 1.7±0.3 | 3.5±0.5 | 3.3±0.3 | 2.0±0.0 | 1.7±0.7 | 5.0±0.0 | 4.7±0.3 | 4.5±0.5 | 3.7±0.3 |
| | T | H | 3.5±0.3 | 1.0±0.5 | 6.0±0.0[f] | 4.0±0.5[f] | 6.0±0.5[f] | 5.3±0.2[f] | 4.0±0.5[F] | 4.0±0.3[f] | 9.0±0.5[F] | 13.3±1.0[F] | 8.0±1.5[F] | 14.0±1.1[F] |
| Arctared creeping red fescue | | C | 4.0±1.0 | 2.7±0.9 | 4.0±0.0 | 3.7±0.3 | 4.3±0.7 | 4.0±0.6 | 4.0±1.0 | 4.0±0.6 | 4.7±0.3 | 4.0±0.6 | 4.3±0.7 | 4.7±0.3 |
| | | H | 19.3±0.9[F] | 16.3±0.5[f] | 18.7±0.5[f] | 21.3±1.4[f] | 26.7±2.3[F] | 28.0±0.8[F] | 19.0±2.0[F] | 22.0±1.6[F] | 28.0±2.9[F] | 26.7±2.5[F] | 27.1±1.1[F] | 33.0±1.5[F] |
| | T | C | 2.0±1.0 | 1.3±0.7 | 4.5±0.2 | 2.7±0.7 | 5.0±0.0 | 4.7±0.3 | 2.0±1.0 | 2.7±0.7 | 4.0±0.5 | 5.0±0.0 | 4.0±0.5 | 4.0±1.0 |
| | T | H | 7.0±1.5 | 3.7±0.9 | 11.5±0.9[f] | 7.3±0.2[f] | 13.0±1.0 | 12.0±1.1[F] | 8.0±0.5 | 8.3±0.2 | 17.0±1.0[F] | 35.8±4.2[F] | 24.5±2.2[F] | 42.7±8.2[F] |
| Meadow foxtail | | C | 4.0±0.6 | 3.3±0.7 | 3.3±0.7 | 3.7±0.3 | 4.3±0.3 | 5.0±0.0 | 2.0±1.2 | 4.3±0.3 | 2.7±1.4 | 4.7±0.3 | 4.0±0.6 | 4.7±0.3 |
| | | H | 35.7±4.3[f] | 36.0±1.1[f] | 30.7±2.0[f] | 47.7±3.7[f] | 42.7±2.0[F] | 63.7±4.5[F] | 38.0±1.0[f] | 53.0±2.9[F] | 29.3±7.8[F] | 62.0±3.3[F] | 49.7±4.5[F] | 58.7±5.8[F] |
| Boreal creeping red fescue | | C | 3.7±0.7 | 5.0±0.0 | 2.7±0.9 | 4.7±0.3 | 2.7±0.9 | 4.3±0.3 | 3.0±0.0 | 3.7±0.7 | 1.7±0.7 | 4.7±0.3 | 1.7±0.9 | 4.3±0.7 |
| | | H | 21.0±1.1 | 32.3±1.0 | 16.0±2.1 | 25.0±0.8[f] | 18.0±1.5 | 27.7±0.8[F] | 21.5±2.2 | 28.3±1.4[f] | 23.3±0.5[f] | 33.7±1.2[f] | 10.0±2.7 | 29.3±0.6[F] |
| Slender wheat-grass | | C | 4.0±0.0 | 3.0±0.0 | 4.0±0.6 | 2.3±0.9 | 3.0±0.6 | 3.3±0.9 | 3.5±0.5 | 2.7±0.3 | 2.0±1.0 | 4.0±0.6 | 4.7±0.3 | 3.7±0.7 |
| | | H | 44.0±2.8[F] | 42.3±1.2[F] | 45.7±4.9[F] | 42.7±3.6[F] | 55.3±2.0[F] | 53.7±3.9[F] | 36.0±4.5[F] | 50.7±1.4[F] | 33.0±8.4[F] | 62.7±0.9[F] | 60.7±3.6[F] | 54.7±5.2[F] |
| | T | C | 0 | 0.7±0.3 | 0 | 1.7±1.2 | 0 | 1.7±0.3 | 0 | 0.3±0.3 | 3.0±1.0 | 3.0±0.0 | 1.5±1.5 | 1.7±0.3 |
| | T | H | 0 | 5.3±1.5 | 0 | 17.0±5.1[f] | 0 | 27.7±3.3[F] | 0 | 5.0±2.5 | 31.0±4.0[F] | 61.0±5.3[F] | 12.0±6.0[f] | 52.7±5.6[F] |
| Engmo timothy | | C | 2.3±0.7 | 3.3±0.3 | 1.7±0.3 | 3.7±0.3 | 1.3±0.8 | 3.3±0.3 | 2.5±0.5 | 4.7±0.3 | 2.0±0.6 | 4.3±0.3 | 2.0±0.6 | 3.7±0.3 |
| | | H | 19.7±1.8[f] | 59.3±0.3[F] | 27.3±3.6[f] | 47.0±1.1[F] | 20.0±5.6[f] | 45.7±2.5[F] | 35.0±8.5[f] | 61.3±3.7[F] | 31.3±1.7[f] | 55.3±2.7[F] | 37.3±3.1[f] | 58.0±3.7[F] |
| Canon Canada bluegrass | | C | 1.3±0.3 | 1.0±0.0 | 2.0±0.0 | 2.7±0.3 | 0.7±0.3 | 2.0±0.6 | 2.5±1.5 | 2.7±0.9 | 3.0±0.6 | 3.0±0.6 | 0.3±0.3 | 3.0±0.6 |
| | | H | 20.3±1.6 | 9.0±0.5 | 21.0±0.8 | 21.7±1.2 | 9.3±2.6 | 24.0±1.9 | 19.5±1.3 | 25.7±2.5 | 16.0±0.5[f] | 27.3±2.3[F] | 3.7±1.8 | 25.0±1.3 |
| Imperial reed canarygrass | | C | 0 | 4.3±0.7 | 0 | 4.0±0.6 | 0.3±0.3 | 3.3±0.9 | 1.0±1.0 | 3.3±0.0 | 0 | 2.3±0.9 | 0.3±0.3 | 3.0±0.6 |
| | | H | 0 | 44.7±1.5 | 0 | 32.7±8.8[f] | 11.0±5.5 | 41.7±1.9 | 11.5±5.7[f] | 45.0±2.1[f] | 0 | 48.3±0.4[f] | 10.0±5.0 | 49.7±6.5[f] |
| Frontier reed canarygrass | | C | 0 | 3.7±0.3 | 0 | 4.0±0.6 | 0 | 3.3±0.3 | 0.3±0.3 | 3.3±0.3 | 0 | 3.3±0.3 | 0.3±0.3 | 2.7±0.3 |
| | | H | 0 | 42.3±2.9 | 0 | 49.3±1.1[f] | 0 | 35.0±2.7 | 5.0±2.5[f] | 50.0±3.7[f] | 0 | 65.0±2.9[f] | 9.0±4.5 | 49.7±6.5[f] |
| Polar Bromegrass | | C | 0.7±0.3 | 1.0±0.0 | 0.7±0.3 | 0.7±0.3 | 1.0±0.0 | 1.3±0.3 | 0 | 1.0±0.0 | 1.3±0.3 | 2.0±0.0 | 1.0±0.0 | 1.7±0.3 |
| | | H | 13.3±3.4 | 23.3±2.9 | 13.3±3.6 | 17.7±4.4 | 29.3±1.8 | 40.0±6.5[f] | 0 | 24.3±1.2 | 26.0±1.6 | 60.0±1.5[f] | 36.0±1.8 | 41.7±3.3[f] |
| Streambank wheat-grass | | C[a] | 0.3±0.3 | 0.7±0.3 | 0 | 1.0±0.0 | 1.0±0.0 | 1.7±0.3 | 0.5±0.5 | 1.3±0.3 | 1.0±0.0 | 2.0±0.0 | 0.7±0.3 | 1.7±0.3 |
| | | H[b] | 8.3±4.1 | 12.7±3.3 | 0 | 23.0±1.8 | 18.7±0.4 | 28.0±2.5 | 6.7±3.8 | 25.0±1.3 | 20.0±0.9 | 32.0±2.9 | 16.3±4.8 | 29.3±2.2 |
| Greenleaf wheat-grass | | C | 0 | 0.3±0.3 | 0 | 0.3±0.3 | 0 | 2.0±0.0 | 0 | 0 | 0 | 2.0±0.6 | 0 | 2.7±1.2 |
| | | H | 0 | 9.0±4.5 | 0 | 5.0±2.5 | 0 | 44.7±3.1[f] | 0 | 0 | 0 | 59.3±6.0[f] | 0 | 59.0±4.1[f] |
| Sawki Russian wildrye | | C | 0 | 0 | 0 | 0 | 0 | 0.7±0.3 | 0 | 0 | 0.3±0.3 | 1.0±0.6 | 0 | 0.7±0.3 |
| | | H | 0 | 0 | 0 | 0 | 0 | 14.0±3.7 | 0 | 0 | 8.3±4.2 | 20.7±5.8 | 0 | 12.3±3.7 |

a Cover Rating classes (amount of row covered by plants): 0 - 0%; 1 - 1 to 10%; 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%.
b H - Height of plant to longest extended leaf or top of seed head.
c Treatments: N - nitrogen; P - phosphorus; L - lime. All applied at 100 kg/ha (≈lb/ac) of element
F Flowering abundant and greater than 5 seed heads/m of row.
f Flowers present at less than 5 seed heads/m of row.
T Species surviving at Tuktoyaktuk

At Tuktoyaktuk, analysis of the cover rating data for the three surviving species revealed no differences between soil types. Fertilizer treatments, however, differed significantly. Lime and Control supported significantly less mean cover (9 and 10 per cent respectively) than the others. The best treatment was N+P with a mean cover of 82 per cent. Nugget Kentucky bluegrass (65 per cent mean cover) and Arctared creeping red fescue (51 per cent) differed significantly from Slender wheatgrass (8 per cent).

Seed heads were not produced in 1970 (Younkin 1972). In 1971, however, flower heads were abundant, especially in the P, N+P and N+P+L fertilizer treatments. Engmo timothy was the sole species to flower in control plots. It, along with Canon Canada bluegrass, Nugget Kentucky bluegrass, Meadow foxtail and Slender wheatgrass flowered abundantly with fertilizer. Flowering was generally greater on mineral than on organic soil. Arctared creeping red fescue and Frontier reed canarygrass did not flower in 1971 (Younkin 1972).

By 1972 (Table 3) the only species not flowering of the 8 examined in 1971 was Frontier reed canarygrass on organic soil. Again, flowering was greater on mineral than organic soil, and with phosphorus containing fertilizer treatments, although the differences were not always great. All three species surviving at Tuktoyaktuk flowered abundantly on mineral soil and less on organic soil. (The viability of collected seed is discussed later).

## 1971 Species and Fertilizer Trials

A second series of species and fertilizer trials was established at Tuktoyaktuk and Inuvik in early June 1971 on both organic and mineral soil. Height and above ground productivity were sampled in mid-August (Younkin, 1972).

These data indicated that height and productivity were generally greater at Inuvik than at Tuktoyaktuk and that mineral soil was better able to support plant growth than was organic soil. These differences could be partly explained by the presence of cooler soil temperatures in organic soils than in mineral and by warmer temperatures at Inuvik than Tuktoyaktuk.

The effect of fertilizers was less clear. Phosphorus alone resulted in greater production than controls but less than when applied in combination with nitrogen. The tallest species, Kall orchardgrass, Frontier reed canarygrass and Fairway crested wheatgrass, usually had the greatest production. A subsequent analysis of variance of the productivity data has generally supported the majority of Younkin's (1972) conclusions. Site differences masked other differences. At

Tuktoyaktuk, mineral soil had a significantly greater productivity than organic soil. Within both soil types 100N-200P was the best fertilizer treatment, (organic 1.5g; mineral 2.8g) 100N-100P intermediate (organic 0.75g; mineral 20g) and 200P and Control equally poor (organic 0.10g and 0.05g respectively; mineral 0.55g and 0.33g respectively). No differences between species were detected on organic soil since all had very low production. On mineral soil, Frontier reed canarygrass and Kall orchardgrass were more productive than Arctared creeping red fescue and Nugget Kentucky bluegrass. Engmo timothy and Fairway crested wheatgrass were neither significantly better than the latter two nor worse than the former two.

The detailed results were more complex at Inuvik. On organic soil, all fertilizer applications were significantly more productive than control, with 100N+200P better than 100N+100P but not better than 200P. Frontier reed canarygrass and Kall orchardgrass had significantly higher production than the other four species. On mineral soil, the results differed. The most effective fertilizer treatment was 100N-100P; the least effective, 200P. The most productive species was Frontier reed canarygrass; the least productive were Engmo timothy, Arctared creeping red fescue and Nugget Kentucky bluegrass.

The cover rating and height data for the late August 1972 sampling of the Inuvik and Tuktoyaktuk plots are presented in Table 4. An analysis of variance was performed on the cover rating data. Site differences were again highly significant. Organic soils had less plant cover than mineral at the 10 per cent level of significance. Analysis within each site revealed that the effects of soils differed at Tuktoyaktuk but not at Inuvik. Fertilizer differences were only detected on organic soil at Tuktoyaktuk, with 100N+100P being best and Control and 200P worst.

Younkin's (1972) speculations on the probable performance of the species in their second year were confirmed. Frontier reed canarygrass did poorly on organic soil but somewhat better on mineral soil. Nugget Kentucky bluegrass and Arctared creeping red fescue were consistently among the best species, when not the best, over all soil types and fertilizers at both sites.

The native species in this experiment showed variable results. Younkin (1972) did not include them in his report since they only emerged sporadically and their growth was poor in 1971. This past year, however, growth was better. Tall arcticgrass (Arctagrostis latifolia) was generally better than bluejoint (Calamagrostis canadensis), significantly so on mineral soil at Tuktoyaktuk (mean cover 33 per cent vs

TABLE 4 MEAN COVER RATING[a] AND HEIGHT[b] OF SPECIES SOWN IN EARLY TO MID-JUNE 1971 AT INUVIK AND TUKTOYAKTUK, N.W.T. ON ORGANIC AND MINERAL SOIL TREATED WITH DIFFERENT FERTILIZERS. DATA ARE MEANS ± STANDARD ERROR FOR 10 HEIGHT MEASUREMENTS AND 1 COVER RATING FOR EACH OF 3 REPLICATES PER TREATMENT. (SAMPLED AUGUST 19, 1972 AT TUKTOYAKTUK AND AUGUST 23 AT INUVIK). SPECIES ARE LISTED IN DESCENDING ORDER OF OVERALL MEAN COVER RATING

| | | | Treatment[c] and Soil Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Control | | $P_2$ | | $N_1P_1$ | | $N_1P_2$ | |
| Species | Site[d] | | Organic | Mineral | Organic | Mineral | Organic | Mineral | Organic | Mineral |
| Arctared creeping red fescue | Inu | C[a] | 4.7±0.3 | 4.3±0.3 | 4.0±0.0 | 5.0±0.0 | 4.0±0.0 | 5.0±0.0 | 5.0±0.0 | 5.0±0.0 |
| | | H[b] | 21.6±0.7[f] | 17.4±0.3[F] | 31.9±1.4[f] | 18.6±0.4[F] | 44.4±0.7[f] | 23.9±0.8[F] | 30.5±0.9[f] | 22.2±0.6[F] |
| | Tuk | C | 3.3±0.7 | 5.0±0.0 | 4.3±0.3 | 5.0±0.0 | 4.3±0.3 | 4.3±0.3 | 5.0±0.0 | 4.3±0.3 |
| | | H | 3.3±0.3 | 5.6±0.3 | 3.8±0.2[F] | 8.7±0.4 | 12.3±0.7 | 10.9±0.6 | 16.1±2.4[f] | 12.2±0.5 |
| Nugget Kentucky bluegrass | Inu | C | 3.3±0.3 | 3.3±0.3 | 3.7±0.3 | 3.7±0.3 | 4.0±0.6 | 3.7±0.7 | 3.3±0.3 | 4.7±0.3 |
| | | H | 12.9±0.5[f] | 11.4±0.5[F] | 26.9±1.3[f] | 10.9±0.3[F] | 21.8±0.4[f] | 16.2±0.6[F] | 25.5±1.0[f] | 12.9±0.6[F] |
| | Tuk | C | 2.0±0.6 | 4.0±0.0 | 2.3±0.3 | 3.3±0.3 | 3.7±0.7 | 4.0±0.4 | 3.7±0.3 | 5.0±0.0 |
| | | H | 2.4±0.2 | 6.0±0.3 | 2.1±0.1 | 6.2±0.4 | 12.0±2.0[f] | 11.5±0.9[F] | 7.8±1.1[F] | 10.0±0.7[F] |
| Tall arcticgrass | Inu | C | 3.7±0.7 | 1.0±0.0 | 5.0±0.0 | 1.3±0.3 | 5.0±0.0 | 2.0±0.6 | 5.0±0.0 | 3.0±0.0 |
| | | H | 29.5±1.5[f] | 24.3±1.3[f] | 47.7±0.9[f] | 14.9±2.0[f] | 52.8±0.8[f] | 33.3±1.3[f] | 49.3±0.7[f] | 39.4±1.1[f] |
| | Tuk | C | 2.0±0.6 | 2.0±0.6 | 1.7±0.3 | 1.0±0.6 | 4.3±0.7 | 3.3±0.3 | 3.3±0.3 | 3.3±0.3 |
| | | H | 3.5±0.9[f] | 5.2±1.1 | 1.2±0.3 | 4.0±0.7 | 29.5±4.2[F] | 30.7±4.1[F] | 18.2±3.6[f] | 25.7±4.1[F] |
| Frontier reed canarygrass | Inu | C | 2.3±0.3 | 3.3±0.9 | 2.0±0.0 | 3.0±0.0 | 2.0±0.0 | 3.7±0.3 | 2.3±0.3 | 3.3±0.3 |
| | | H | 30.5±2.0 | 48.4±2.4[f] | 37.8±1.7 | 41.9±1.5[f] | 44.1±0.7 | 77.7±1.9[f] | 47.6±2.1 | 62.4±2.9[F] |
| | Tuk | C | 1.7±0.9 | 2.7±0.3 | 1.0±0.6 | 3.7±0.3 | 1.3±0.3 | 2.7±0.3 | 1.0±0.6 | 3.0±0.6 |
| | | H | 2.8±0.2 | 7.1±0.5 | 4.6±0.8 | 8.6±0.7 | 7.2±0.8 | 12.1±0.9 | 5.7±0.5 | 12.3±1.1 |
| Bluejoint | Inu | C | 3.3±0.7 | 1.0±0.0 | 3.7±0.3 | 1.0±0.0 | 3.3±0.3 | 1.3±0.3 | 3.7±0.3 | 1.3±0.3 |
| | | H | 31.9±1.0[F] | 26.4±0.8[f] | 49.9±0.7[F] | 29.4±1.5[F] | 53.5±6.6[F] | 25.0±2.2[F] | 48.6±1.0[F] | 37.4±0.8[F] |
| | Tuk | C | 1.7±0.3 | 0.7±0.3 | 1.0±0.0 | 0.7±0.3 | 3.3±0.7 | 0.7±0.3 | 2.0±0.0 | 1.3±0.3 |
| | | H | 5.1±1.0[f] | 1.8±0.4 | 3.3±0.5 | 2.3±0.4 | 22.0±3.9[F] | 5.3±1.5[f] | 17.0±2.8[F] | 14.6±2.8[F] |
| Engmo timothy | Inu | C | 1.0±0.0 | 2.0±0.6 | 1.0±0.0 | 2.3±0.3 | 1.0±0.0 | 1.7±0.7 | 1.0±0.0 | 2.0±0.0 |
| | | H | 19.9±1.6[f] | 30.9±1.2[f] | 30.0±1.5[f] | 29.1±1.8[F] | 30.2±1.2[f] | 28.5±0.6[f] | 33.7±1.4[f] | 27.9±1.0[f] |
| | Tuk | C | 1.3±0.3 | 1.0±0.0 | 0.3±0.3 | 1.7±0.3 | 0.3±0.3 | 1.3±0.3 | 0.7±0.3 | 1.0±0.0 |
| | | H | 2.8±0.6 | 3.6±0.6 | 7.2±0.5 | 5.5±0.7 | 6.1±0.2 | 4.6±0.6 | 4.8±0.5 | 3.7±0.6 |
| Kall orchardgrass | Inu | C | 0 | 3.7±0.9 | 0 | 4.3±0.3 | 0 | 3.3±0.7 | 0 | 3.3±0.7 |
| | | H | 0 | 28.7±1.0 | 0 | 31.2±0.8 | 0 | 40.0±2.6 | 0 | 31.6±0.8 |
| | Tuk | C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fairway crested wheatgrass | Inu | C | 0 | 1.7±0.3 | 0 | 1.0±0.0 | 0 | 1.0±0.0 | 0 | 1.5±0.5 |
| | | H | 0 | 44.0±0.9 | 0 | 39.7±1.1 | 0 | 35.8±1.9 | 0 | 52.9±1.3 |
| | Tuk | C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

a Cover Rating classes (amount of row covered by plants): 0 - 0%; 1 - 1 to 10%; 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%.

b H - Height of plant to longest extended leaf or top of seed head.

c Treatments: N - Nitgogen; P - phosphorus. 1 - 100 kg/ha (≈lb/ac) and 2 - 200 kg/ha of element.

d Site: Inu - Inuvik; Tuk - Tuktoyaktuk.

F Flowering abundant, greater than 10 seed heads/m of row.

f Flowers present at less than 10 seed heads/m of row.

4 per cent) and on organic soil at Inuvik (94 per cent vs 65 per cent). Both grew poorly to moderately well on organic soil at Tuktoyaktuk (45 per cent and 22 per cent respectively) but very poorly on mineral soil at Inuvik (19 per cent and 7 per cent). This last site and soil type combination was anomalous in other respects. It was the only one where Fairway crested wheatgrass survived and on which Kall orchardgrass was abundant. These anomalies may be partly explained by the fact that the site was on a dry, warm south-facing slope, climatically similar to more southerly latitudes.

Flowers were not noted on these plots in 1971, but were present in 1972. Differences similar to those in the 1970 plots were noted. Fertilizer treatments with nitrogen and phosphorus combined generally had more flowers than P alone or Control. Mineral soil was better than organic soil at both sites and Tuktoyaktuk generally had fewer flowers than Inuvik. The species flowering were Nugget Kentucky bluegrass, Arctared creeping red fescue, bluejoint, tall arcticgrass and Engmo Timothy.

In summary, the results from both sets of species and fertilizer trials indicate the following:

(a) Growth and flowering at Inuvik is greater than at Tuktoyaktuk, probably because of a better climate (see Table 1).

(b) Mineral soil is better able to support plant growth and flowering than organic soil, irrespective of site.

(c) Fertilizer effects are often lost by the second or third year. However, a combination of nitrogen and phosphorus appears best in promoting growth in the first year or two.

(d) The best species by far are arctared creeping red fescue and Nugget Kentucky bluegrass.

(e) The native grasses are moderately to highly successful by their second year.

(f) Kall orchardgrass, Frontier reed canarygrass, Fairway crested wheatgrass and Engmo timothy may do well in the first year but overwinter poorly and die out.

(g) Flowers are produced by species tested in the north especially if they are fertilized. (The viability of any seed produced is discussed later in this section).

TABLE 5 COVER FOR THE SPECIES TRIALS SEEDED IN JUNE, 1971 FOR DIFFERENT POSITIONS OVER THE PEAT ORGANIC SOIL BERM OF THE GAS TEST LOOP AT PRUDHOE BAY, ALASKA. DATE ARE GIVEN AS MEANS ± STANDARD ERROR FOR THREE REPLICATES OF EACH SPECIES ON AUGUST 11, 1972

| | BERM POSITION | | | | |
|---|---|---|---|---|---|
| Species | Bottom | W Facing | Top | E Facing | Bottom |
| | | | Cover (%) | | |
| Arctared creeping red fescue | 17.7±5.0 | 24.3±5.4 | 2.3±1.4 | 8.0±3.6 | 8.0±1.2 |
| Boreal creeping red fescue | 13.0±4.7 | 20.0±2.9 | 0 | 7.7±1.2 | 6.7±1.3 |
| Nugget Kentucky bluegrass | 24.0±6.6 | 21.7±3.3 | 0.5±0.3 | 11.7±3.3 | 6.3±1.8 |
| Meadow foxtail | 2.3±0.7 | 2.5±1.3 | 0.3±0.2 | 1.2±0.4 | 1.0±0.0 |
| Climax timothy | 0.3±0.2 | 0.5±0.0 | 0 | 0.5±0.0 | 0.5±0.3 |
| Sawki Russian wildrye | 0.5±0.0 | 0.3±0.2 | 0 | 0.3±0.2 | 0.2±0.2 |
| Frontier reed canarygrass | 0.5±0.3 | 0.8±0.6 | 0 | 0.2±0.2 | 0.2±0.2 |
| Fairway crested wheatgrass | 2.3±1.3 | 1.2±0.4 | 0 | 0.5±0.0 | 0.2±0.2 |
| Falcata alfalfa | 0.5±0.3 | 1.0±0.0 | 0.2±0.2 | 0.3±0.2 | 0.5±0.0 |
| Aurora alsike clover | 2.3±0.3 | 1.7±0.3 | 0 | 0.5±0.0 | 0.3±0.2 |
| Leo birdsfoot trefoil | 0.8±0.2 | 1.0±0.0 | 0.2±0.2 | 0.5±0.0 | 0.7±0.2 |

TABLE 6 COVER AND HEIGHT FOR THE SPECIES TRIALS SEEDED IN JUNE 1971 FOR DIFFERENT POSITIONS OVER THE GRAVEL AND MINERAL SOIL BERM OF THE OIL TEST LOOP AT INUVIK, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR THREE REPLICATES OF EACH SPECIES ON AUGUST 23, 1972

| | | BERM POSITION | | | | |
|---|---|---|---|---|---|---|
| Species | | Bottom | N.Facing | Top | S.Facing | Bottom |
| | | Cover (%) and Height (cm) | | | | |
| Arctared creeping red fescue | C[a] | 4.7±0.3 | 5.3±0.3 | 0.7±0.3 | 1.0±0.0 | 3.3±0.9 |
| | H[a] | 9.3±0.3 | 10.0±1.2 | 3.0±1.5 | 7.3±1.4 | 10.0±2.5 |
| Boreal creeping red fescue | C | 8.3±1.7 | 8.0±2.3 | 0 | 2.7±1.2 | 4.0±1.0 |
| | H | 9.7±2.2 | 6.7±0.3 | 0 | 9.3±1.2 | 12.0±2.5 |
| Nugget Kentucky bluegrass | C | 3.3±0.9 | 1.7±0.3 | 0 | 3.0±1.2 | 4.3±1.2 |
| | H | 8.7±2.7 | 4.3±1.3 | 0 | 7.7±2.3 | 6.3±0.7 |
| Meadow foxtail | C | 7.0±3.0 | 2.3±1.3 | 0 | 1.0±0.0 | 3.0±1.2 |
| | H | 16.6±4.3 | 7.3±1.3 | 0 | 12.7±2.7 | 18.0±6.8 |
| Climax timothy | C | 9.0±1.5 F[b] | 2.5±1.8 | 0 | 5.0±1.7 F | 3.2±0.9 F |
| | H | 13.3±1.2 | 6.3±1.4 | 0 | 22.0±3.0 | 15.7±3.2 |
| Sawki Russian wildrye | C | 5.7±1.4 | 3.3±1.2 | 1.0±0.0 | 5.7±2.3 | 2.0±0.6 |
| | H | 14.0±1.0 | 16.3±3.4 | 9.0±2.0 | 17.7±3.2 | 14.7±2.7 |
| Frontier reed canarygrass | C | 1.0±0.0 | 0.3±0.3 | 0.3±0.3 | 1.3±0.3 | 4.0±0.6 |
| | H | 4.3±1.4 | 2.7±2.7 | 2.7±2.7 | 16.7±4.2 | 13.3±4.2 |
| Fairway crested wheatgrass | C | 2.0±0.6 | 0.7±0.2 | 0 | 1.0±0.6 | 1.2±0.4 |
| | H | 11.7±2.0 | 9.3±3.0 | 0 | 12.3±6.2 | 10.3±1.4 |
| Falcata alfalfa | C | 1.5±0.5 | 0.8±0.2 | 0.3±0.3 | 6.3±2.7 F | 1.3±0.3 |
| | H | 2.7±1.2 | 2.0±0.6 | 1.3±1.3 | 20.3±1.8 | 8.0±3.2 |
| Aurora alsike clover | C | 0.5±0.3 | 0.2±0.2 | 0 | 0.5±0.3 | 0.8±0.2 |
| | H | 1.0±0.6 | 0.3±0.3 | 0 | 1.0±0.6 | 1.7±0.3 |
| Leo birdsfoot trefoil | C | 0.7±0.2 | 0 | 0 | 0 | 0.5±0.3 |
| | H | 1.7±0.7 | 0 | 0 | 0 | 2.7±1.8 |

a C - Cover (%); H - Height (cm)

b F - Some flowers present in at least one replicate; all other species were vegetative.

## Experiments Established by Wein

### Species Trials Over Berms

The cover data obtained from the mid-August sampling of the species trials over the low, cold, gas test loop at Prudhoe Bay, Alaska (Walker 1972), are given in Table 5. Only three species had significant cover over the peat fill berm. These were two creeping red fescues, Arctared and Boreal, and Nugget Kentucky bluegrass. They provided up to 25 per cent cover on the west side of the berm but only up to 11 per cent on the east. Wein (1971a) noted that seedlings were more abundant on the west than on the east side in 1971. The other grasses and the legumes sown generally had cover of only 1 to 2 per cent. None of the plots at Prudhoe Bay had any flower heads. This was mainly due to continual grazing by caribou throughout the summer.

In contrast to the low cover obtained in the present study, a much greater cover, approaching 80 to 100 per cent, for the best species (among them Arctared creeping red fescue and Nugget Kentucky bluegrass) was noted in plots also established in 1971 over the same berm by Dr. William W. Mitchell of the University of Alaska. The increase was partly due to higher seeding rates (27 to 38 kg/ha vs 5.5 to 11 kg/ha in the present study). Initial fertilizer application differed predominately in Mitchell's use of 67 kg/ha of k20 while Wein (1971a) did not add potassium fertilizer. However, in 1972, Mitchell re-fertilized his plots with 670 kg/ha of 10-20-20 fertilizer. This, no doubt, contributed quite significantly to the greater success in plant establishment, and thus cover (W.W. Mitchell, 1972, personal communication).

The cover and height data obtained from the late-August sampling of the species trials over the hot, oil test loop berm (3 m tall) at Inuvik (Hall et al. 1972), are presented in Table 6. No species had a mean cover greater than 9 per cent at any position over the gravel and mineral soil berm. The best species on the basis of total cover over the berm were Boreal creeping red fescue, Climax timothy and Sawki Russian wildrye. Legumes were all but insignificant except for two of the three replicates on the north-facing side of the berm where a clump of Falcata alfalfa became established and flowered in each plot. The only other species to flower was Climax timothy. Overall, growth was quite poor with cover generally greater on the north than on the drier south-facing side.

Cover and height data (end of August sampling) of the species trials over the low, 1.5 m berms of the cold 9.5°C and warm 18°C gas test pipes at Norman Wells (Walker 1972) are presented in Tables 7 and 8 respectively. Both berms are silty mineral soil.

TABLE 7. COVER AND HEIGHT FOR THE SPECIES TRIALS SEEDED IN JUNE 1971 FOR DIFFERENT POSITIONS OVER THE SILTY MINERAL SOIL BERM OF THE COLD (15° F) GAS TEST LOOP AT NORMAN WELLS, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR THREE REPLICATES, ON AUGUST 30, 1972

| | | BERM POSITION | | | | |
|---|---|---|---|---|---|---|
| Species | | Bottom | N.Facing | Top | S.Facing | Bottom |
| | | Cover (%) and Height (cm) | | | | |
| Arctared creeping red fescue | C[a] | 41.7±13.0 F[b] | 21.7±1.7 F | 5.3±1.8 | 26.7±1.7 F | 40.0±10.4 F |
| | H[a] | 20.0± 4.0 | 18.3±3.3 | 6.3±3.1 | 15.7±1.2 | 19.0± 2.1 |
| Boreal creeping red fescue | C | 20.0±5.0 | 20.7±4.3 | 0 | 22.3±5.4 f[b] | 20.0±5.8 f |
| | H | 15.7±1.4 | 16.0±3.8 | 0 | 15.3±1.7 | 17.0±2.1 |
| Nugget Kentucky bluegrass | C | 15.7±2.3 F | 25.0±8.7 F | 2.7±2.7 | 17.3±2.7 F | 16.7±2.4 F |
| | H | 8.3±1.8 | 12.0±3.0 | 4.3±4.3 | 9.7±1.8 | 9.0±1.0 |
| Meadow foxtail | C | 7.3±3.9 | 6.0± 1.0 | 1.7±1.7 | 9.0±1.0 | 11.7±2.0 F |
| | H | 19.0±5.0 | 17.0± 4.0 | 5.0±5.0 | 18.0±1.2 | 40.3±0.9 |
| Climax timothy | C | 10.0±1.2 | 4.3± 0.7 | 0 | 5.3±2.2 | 10.0±1.2 f |
| | H | 12.3±2.2 | 10.5± 1.3 | 0 | 7.3±1.4 | 19.7±4.9 |
| Sawki Russian wildrye | C | 10.7±4.8 | 9.0± 2.0 | 4.3±0.7 | 12.3±1.4 f | 11.6±4.4 |
| | H | 16.3±2.6 | 22.0± 5.0 | 16.0±2.6 | 26.6±4.4 | 17.3±2.8 |
| Frontier reed canarygrass | C | 6.3±2.7 | 0.7± 0.3 | 0 | 1.0±0.6 | 10.3±1.7 f |
| | H | 27.7±3.9 | 7.7± 3.9 | 0 | 5.7±3.0 | 45.3±14.1 |
| Fairway crested wheatgrass | C | 2.3±0.7 | 2.0± 0.6 | 0.7±0.7 | 3.0±0.6 | 3.7±0.3 |
| | H | 11.3±1.8 | 12.3± 1.2 | 6.3±6.3 | 16.0±1.7 | 13.7±3.8 |
| Falcata alfalfa | C | 4.0±0.6 f | 10.0± 3.6 f | 0 | 11.7±4.9 f | 11.7±1.7 f |
| | H | 14.0±1.0 | 12.0± 1.2 | 0 | 17.0±6.6 | 23.7±5.8 |
| Aurora alsike clover | C | 9.3±3.5 f | 1.7± 0.3 | 0.7±0.7 | 2.7±0.9 | 1.3±0.3 |
| | H | 8.0±3.2 | 2.3± 1.3 | 2.0±2.0 | 3.0±0.6 | 1.7±0.3 |
| Leo birdsfoot trefoil | C | 1.0±1.0 | 2.3± 0.7 | 0 | 1.3±0.3 | 2.3±0.7 |
| | H | 2.0±2.0 | 5.0± 1.2 | 0 | 7.0±1.0 | 6.7±0.3 |

a C - Cover (%); H - Height (cm)

b F - Flowering common in all three replicates; f - few flowers and not in all replicates. Where no symbol is given, all plants were vegetative.

TABLE 8. COVER AND HEIGHT FOR THE SPECIES TRIALS SEEDED IN JUNE 1971 FOR DIFFERENT POSITIONS OVER THE SILTY MINERAL SOIL BERM OF THE HOT (65° F) GAS TEST LOOP AT NORMAN WELLS, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR THREE REPLICATES, ON AUGUST 30, 1972.

| Species | | BERM POSITION | | | | |
|---|---|---|---|---|---|---|
| | | Bottom | N.Facing | Top | S.Facing | Bottom |
| | | Cover (%) and Height (cm) | | | | |
| Arctared creeping red fescue | C[a] | 58.3±13.0 F[b] | 53.3±8.8 F | 15.7±2.3 F | 45.0±7.6 F | 50.0±5.8 F |
| | H[a] | 28.0± 4.0 | 21.3±1.2 | 16.7±3.7 | 16.0±1.2 | 20.3±1.4 |
| Boreal creeping red fescue | C | 56.7±13.6 f[b] | 41.7±8.3 F | 12.3±0.3 f | 31.7±10.1 f | 68.3±4.4 f |
| | H | 27.3± 2.3 | 21.3±1.8 | 11.7±1.7 | 14.3± 3.5 | 26.7±0.9 |
| Nuggett Kentucky bluegrass | C | 53.3±17.6 F | 24.3±13.0 f | 11.7±2.0 F | 19.0±3.0 F | 56.7±10.9 F |
| | H | 16.0± 5.0 | 8.3± 1.2 | 9.0±0.6 | 9.3±1.3 | 12.0± 2.0 |
| Meadow Foxtail | C | 20.0± 2.9 f | 13.3± 1.7 f | 9.3±1.8 | 13.0±1.0 f | 16.0± 1.0 F |
| | H | 68.7± 3.7 | 49.0± 9.8 | 23.0±2.5 | 31.3±5.2 | 74.0±10.8 |
| Climax timothy | C | 20.0± 5.0 F | 20.7± 7.2 F | 10.0±0.0 F | 14.7±6.1 f | 15.7±2.3 F |
| | H | 46.7± 9.2 | 64.0± 1.5 | 58.0±10.7 | 27.3±11.0 | 43.7±2.2 |
| Sawki Russian wildrye | C | 14.3± 3.5 | 11.7± 1.7 | 9.0±2.1 | 11.7±2.0 | 15.7±4.7 |
| | H | 20.0± 5.7 | 22.3± 6.7 | 28.0±9.8 | 23.3±5.5 | 25.7±3.4 |
| Frontier reed canarygrass | C | 12.3± 4.3 f | 16.7± 4.4 F | 6.7±3.3 | 16.7±1.7 F | 12.0±3.5 f |
| | H | 54.7±10.7 | 79.3±11.7 | 48.7±24.8 | 70.7±10.4 | 61.3±9.2 |
| Fairway crested wheatgrass | C | 6.0±2.1 | 13.3± 2.4 | 10.7±4.3 f | 11.3±0.7 | 10.0±1.2 f |
| | H | 32.0±2.1 | 40.3± 3.2 | 25.7±4.9 | 37.3±8.1 | 34.3±7.4 |
| Falcata alfalfa | C | 16.7±4.4 F | 41.7±21.8 F | 20.7±15.1 F | 31.7±9.3 F | 60.0±14.4 F |
| | H | 24.3±6.4 | 28.3± 7.5 | 22.0±11.2 | 30.3±5.2 | 38.0± 8.3 |
| Aurora alsike clover | C | 20.3±10.2 f | 81.7±4.4 F | 9.0±8.0 f | 55.0±25.0 F | 54.0±21.0 F |
| | H | 22.0±11.6 | 47.7±1.2 | 8.7±6.7 | 32.7±13.8 | 26.3± 3.5 |
| Leo birdsfoot trefoil | C | 2.5±0.5 | 7.0±3.0 f | 0 | 1.5±0.5 | 5.5±4.5 f |
| | H | 6.0±0.0 | 7.5±1.5 | 0 | 8.0±1.0 | 11.5±1.5 |

[a] C - Cover (%); H - Height (cm)

[b] F - Flowering common in all three replicates; f - few flowers and not in all replicates. Where no symbol is given, all plants were vegetative.

The three best grasses over the cold berm were Arctared and Boreal creeping red fescue and Nugget Kentucky bluegrass. These usually covered 20 to 25 per cent of the berm, except for the bottom of the south-facing side where Arctared fescue had a 40 per cent cover. The rest of the grasses had, at most, 12 per cent cover. Falcata alfalfa was the best legume, reaching 12 per cent cover on three of the four berm positions. Leo birdsfoot trefoil was consistently the poorest of the 11 species tested. Overall, there was little difference between north and south exposures on the berm. Flowering (Table 7) was common and abundant for Arctared creeping red fescue, Nugget Kentucky bluegrass and Falcata alfalfa. Other species flowering less abundantly were Boreal creeping red fescue, Meadow foxtail and Aurora alsike clover.

The three most abundant grasses over the warm pipe berm were once again Arctared and Boreal creeping red fescue and Nugget Kentucky bluegrass. These had cover ranging from 45 to 58 per cent, 31 to 68 per cent and 20 to 56 per cent respectively, depending on the position on the berm. Cover was generally lower on the sides than at the base of the berm. The other grasses usually covered 10 to 20 per cent of the berm, although Meadow foxtail reached 57 per cent at the bottom of both sides of the berm. The legumes, Aurora alsike clover and Falcata alfalfa, grew quite extensively at this site with clover approximately equalling or surpassing the creeping red fescues at all positions except the northern base of the berm. Alfalfa was not as abundant as clover. Leo birdsfoot trefoil again was the least successful of the 11 species tested. Mean cover on the north was consistently greater than or equal to that on the south-facing side, but the variability of the individual readings was quite large. Flowering (Table 8) was common and abundant for all species except Sawki Russian wildrye, which did not flower, and Fairway crested wheatgrass and Leo birdsfoot trefoil which flowered at only two positions and in two replicates.

Plant cover at the top of the berms was much lower than on the sides, when not totally absent. The top is the driest and most exposed berm position and plant establishment and growth were hindered there because it was often used as a walkway to monitor sensing instruments (e.g. especially Inuvik) and because it also developed drying cracks (e.g. Norman Wells, Walker 1972). Thus most of the plant cover shown as occuring at the top in the previous tables (5, 6, 7, 8) came from plants established on the upper berm sides.

Table 9 contains the rankings of the species tested over all four berms, based on cover. The lower the rank, the greater was the cover provided by that species. The two creeping red fescue varieties, Arctared and Boreal, followed closely by Nugget Kentucky bluegrass are, by far, the

TABLE 9 - RANKING OF THE SPECIES TESTED OVER BERMS AT THREE TEST SITES

| | SITE[a] AND RANK[b] | | | | | |
|---|---|---|---|---|---|---|
| Species | Prudhoe Bay | Inuvik | Norman Wells Cold | Norman Wells Hot | Mean[c] Rank | Overall[d] Rank |
| Arctared creeping red fescue | 1 | 5 | 1 | 1.5 | 2.08 | 1.5 |
| Boreal creeping red fescue | 3 | 1 | 2 | 1.5 | 2.12 | 1.5 |
| Nugget Kentucky bluegrass | 2 | 4 | 3 | 4.5 | 2.71 | 3 |
| Meadow foxtail | 4 | 6 | 6 | 7 | 5.33 | 4 |
| Climax timothy | 9 | 2 | 7 | 6 | 6.04 | 5 |
| Sawki Russian wildrye | 10.5 | 3 | 4 | 9 | 6.67 | 8 |
| Frontier reed canarygrass | 10.5 | 8 | 10 | 8 | 8.75 | 9.5 |
| Fairway crested wheatgrass | 7 | 9 | 8.5 | 10 | 8.71 | 9.5 |
| Falcata alfalfa | 8 | 7 | 5 | 4.5 | 6.38 | 6 |
| Aurora alsike clover | 5 | 10 | 8.5 | 3 | 6.58 | 7 |
| Leo birdsfoot trefoil | 6 | 11 | 11 | 11 | 9.79 | 11 |

a Site: Prudhoe Bay, 25°F gas loop; Inuvik, 150+°F oil loop; Norman Wells, gas loop - Cold, 15°F; Hot, 65°F.

b Ranking based on cover at each berm position, except top, at each site. When cover was the same for several species, the ranks involved were averaged and each species was given the same value.

c Mean rank included the individual rankings shown and the rankings obtained from total cover of each species at each site.

d Overall rank based on mean rank values, with those differing by less than 0.05 being deemed equal.

TABLE 10 COVER RATING[a] AND HEIGHT[b] FOR SPECIES SOWN ON DIFFERENT DATES THROUGHOUT THE SUMMER OF 1971 NEAR NORMAN WELLS, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR FOUR REPLICATES OF EACH SEEDING DATE, UNLESS OTHERWISE NOTED. SAMPLED AUGUST 28, 1972.

| Species | | SEEDING DATE: June 13 | July 1 | July 25 | August 14[c] | August 21[c] |
|---|---|---|---|---|---|---|
| | | Cover Rating and Height (cm) | | | | |
| Arctared creeping red fescue | C[a] | 4.3±0.5[F] | 4.0±0.7[F] | 4.0±0.0 | 3.7±0.7 | 3.3±0.3 |
| | H[b] | 22.0±1.7 | 19.0±3.3 | 16.5±0.5 | 10.3±0.9 | 13.0±0.6 |
| Nugget Kentucky bluegrass | C | 5.0±0.0[F] | 5.0±0.0[F] | 4.2±0.2[F] | 3.7±0.9 | 2.7±0.3 |
| | H | 17.0±2.8 | 15.5±3.1 | 13.8±1.2 | 8.3±2.7 | 6.7±0.7 |
| Climax timothy | C | 2.8±0.7[f] | 3.0±1.2[f] | 3.8±0.2[F] | 3.7±0.7[F] | 3.3±0.3[F] |
| | H | 29.5±2.3 | 24.2±5.6 | 43.5±3.9 | 34.7±1.7 | 24.0±3.8 |
| Sawki Russian wildrye | C | 3.0±0.7 | 3.8±0.5[f] | 3.2±0.5 | 3.3±0.3 | 2.7±0.3 |
| | H | 22.8±3.4 | 24.2±3.7 | 22.2±1.5 | 16.3±3.0 | 15.0±2.0 |
| Aurora alsike clover | C | 1.5±0.2[f] | 1.2±0.2[f] | 1.5±0.3[f] | 1.3±0.3 | 1.7±0.3 |
| | H | 4.0±0.8 | 4.0±0.7 | 4.7±1.3 | 1.7±0.7 | 2.7±0.3 |
| Tall arcticgrass | C | 3.8±0.2[F] | 3.2±0.2[f] | 2.0±0.4 | 2.3±0.3 | 1.7±0.3 |
| | H | 31.0±0.6 | 31.0±6.3 | 16.2±0.7 | 12.0±5.6 | 9.0±2.1 |
| Frontier reed canarygrass | C | 2.8±0.6 | 4.0±0.4 | 1.8±0.7 | 1.3±0.9 | 1.7±0.3 |
| | H | 43.7±0.4 | 49.5±6.3 | 29.5±8.4 | 29.5±8.4 | 28.3±3.7 |
| Bluejoint | C | 3.2±0.6[F] | 2.7±0.7[Fc] | 1.0±0.0[f] | 1.7±0.3 | 2.0±0.6 |
| | H | 25.5±5.5 | 22.0±2.1 | 16.0±2.6 | 8.0±0.0 | 8.0±1.2 |
| Fairway crested wheatgrass | C | 1.8±0.5[f] | 1.5±0.5[f] | 1.5±0.3[f] | 3.0±0.6[f] | 2.0±1.0[f] |
| | H | 28.5±6.4 | 25.8±8.6 | 39.2±4.2 | 41.0±4.2 | 30.7±8.1 |
| Falcata alfalfa | C | 1.2±0.2[f] | 2.0±0.6[fc] | 1.0±0.0 | 1.0±0.0 | 1.3±0.3 |
| | H | 5.2±2.0 | 12.3±5.0 | 3.0±0.9 | 1.7±0.3 | 3.3±1.2 |
| Leo birdsfoot trefoil | C | 1.0±0.0[c] | 1.5±0.3 | 1.0±0.0 | 1.0±0.0 | 0.7±0.3 |
| | H | 4.0±1.5 | 3.5±0.6 | 2.2±0.6 | 2.7±1.2 | 2.3±1.2 |
| Cottongrass | C | 0.5±0.3[S] | 0.8±0.5[S] | 0.3±0.3[S] | 1.0±0.6[S] | 0.3±0.3[S] |
| | H | 1.8±1.4 | 1.5±1.0 | 0.3±0.3 | 0.7±0.3 | 0.3±0.3 |

a C - Cover Rating classes (amount of row covered by plants): 0 - 0%; 1 - 1 to 10%; 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%

b H - Height of plant to longest leaf or top of seed head.

c Based on only 3 replications; one was washed out, or not sown.

F Flowering abundant; present in all replicates; few plants solely vegetative.

f Flowers present in some replicates; more than 50% of plants vegetative.

S Seedling

TABLE 11 COVER RATING[a] AND HEIGHT[b] FOR SPECIES SOWN ON DIFFERENT DATES THROUGHOUT THE SUMMER OF 1971 NEAR INUVIK, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR FOUR REPLICATES OF EACH SEEDING DATE. SAMPLED AUGUST 25,1972

| Species | | SEEDING DATE June 6 | June 28 | July 17 | August 8 | August 26 |
|---|---|---|---|---|---|---|
| | | Cover Rating and Height (cm) | | | | |
| Arctared creeping red fescue | C[a] | 4.0±1.0[F] | 4.8±0.2[f] | 5.0±0.0[f] | 3.8±0.2 | 2.0±0.4 |
| | H[b] | 22.5±2.8 | 20.0±2.5 | 23.8±3.6 | 14.0±1.1 | 6.8±0.9 |
| Nugget Kentucky bluegrass | C | 4.0±0.7[F] | 3.5±1.0[F] | 4.0±1.0[F] | 3.5±0.6[f] | 1.8±0.5 |
| | H | 16.2±3.2 | 12.5±2.0 | 12.2±1.0 | 11.8±1.0 | 6.8±1.0 |
| Climax timothy | C | 1.8±0.8[F] | 1.5±0.5[F] | 1.2±0.2[f] | 3.0±0.4[F] | 3.8±0.9[f] |
| | H | 29.8±13.2 | 26.2±6.7 | 33.8±7.1 | 34.8±5.2 | 23.5±1.6 |
| Sawki Russian wildrye | C | 2.8±0.8 | 2.2±0.8 | 4.0±0.4 | 1.0±0.7 | 0.8±0.2 |
| | H | 35.0±8.0 | 28.0±4.5 | 24.0±3.6 | 10.5±6.3 | 13.2±4.9 |
| Aurora alsike clover | C | 4.5±0.5[F] | 2.2±0.8[f] | 3.5±0.3[f] | 3.0±0.4 | 3.8±0.2 |
| | H | 18.0±3.7 | 10.0±2.9 | 7.8±3.1 | 6.8±1.6 | 10.5±1.2 |
| Tall arcticgrass | C | 1.8±0.5[f] | 1.5±0.5[f] | 2.2±0.2 | 1.2±0.2 | 1.0±0.4 |
| | H | 27.5±9.9 | 24.8±7.3 | 23.5±3.8 | 7.0±3.3 | 5.0±1.7 |
| Frontier reed canarygrass | C | 3.8±0.5 | 0.2±0.2 | 0.8±0.2 | 1.8±0.2 | 2.8±0.2 |
| | H | 53.0±10.0 | 4.5±4.5 | 21.8±9.2 | 25.8±4.5 | 35.8±5.8 |
| Bluejoint | C | 2.2±0.5[F] | 2.0±0.6[F] | 1.8±0.2[f] | 1.0±0.0 | 1.2±0.2 |
| | H | 32.8±8.8 | 29.0±6.9 | 25.2±5.9 | 8.2±1.0 | 7.8±0.5 |
| Fairway crested wheatgrass | C | 0.8±0.5 | 0.2±0.2 | 0.5±0.3 | 0.5±0.3 | 2.0±0.7 |
| | H | 21.2±12.9 | 4.2±4.2 | 18.8±13.7 | 12.8±5.3 | 33.5±12.0 |
| Falcata alfalfa | C | 2.2±0.5[f] | 1.8±0.5[f] | 2.2±0.5[f] | 1.0±0.0 | 1.0±0.0 |
| | H | 19.5±2.7 | 13.0±2.1 | 15.0±4.6 | 9.0±2.7 | 13.5±4.7 |
| Leo birdsfoot trefoil | C | 3.2±0.8[F] | 1.2±0.2[f] | 1.2±0.2 | 1.5±0.5[f] | 1.5±0.5[f] |
| | H | 20.8±3.7 | 10.5±3.4 | 6.2±1.3 | 13.5±5.8 | 10.8±3.8 |
| Cottongrass | C | 0 | 0 | 0 | 0.5±0.3[S] | 0 |
| | H | 0 | 0 | 0 | 1.5±0.9 | 0 |

a Cover Rating Classes C (amount of row covered by plants): 0 - 0%, 1 - 1 to 10%; 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%.

b H - Height of plant to longest leaf or top of seed head.

F Flowering abundant, present in all replicates; few plants solely vegetative.

f Flowers present in some replicates, more than 50% of plants vegetative.

S Seedlings

superior species over all three sites. They have overwintered most successfully and grown most abundantly in the second summer after seeding. The least successful species have been Frontier reed canarygrass and Fairway crested wheatgrass and the legume Leo birdsfoot trefoil. All other species were intermediate with Meadow foxtail being the best of these. Younkin (1972), in his evaluation of the 1970 plots at the end of their second year at Inuvik, also found that the two creeping red fescues and the bluegrass were among the best species and reed canarygrass among the least successful.

Date of Seeding

Eleven species, 5 agronomically developed grasses, 3 legumes, and 3 native species - 2 grasses and a sedge - (See subsequent tables for names), were sown in rows at different dates throughout the summer of 1972 at Norman Wells, Inuvik and Prudhoe Bay.

Height flowering and cover ratings for each species at the end of August 1972 at Norman Wells are in Table 10. These plots were seeded in silty mineral soil. Most grass species were successful in establishing on the first (spring) planting date. Success (based on cover rating) often decreased through subsequent dates. The three legumes were uniformly unsuccessful for all seeding dates. The two native grasses, tall arcticgrass and bluejoint, were quite successful for the two earliest planting dates, being second only to the two agronomically developed northern varieties, Arctared creeping red fescue and Nugget Kentucky bluegrass. Flowering decreased with later seeding dates for all species except Climax timothy and Fairway crested wheatgrass. This year, cottongrass seedlings (Eriophorum vaginatum) did emerge unlike 1971 (Wein 1971a:14). However, they were quite small and did not provide significant ground cover.

The data from the late August sampling of the Inuvik plots are presented in Table 11. This site was seeded on mineral soil in a cleared area of a dry, warm south-facing slope. This, helps explain why it was the sole site of the three where the legumes, especially aurora alsike clover, were abundant and successfully established. For the first seeding date, clover had the greatest cover along the row, although the grasses, Arctared creeping red fescue and Nugget Kentucky bluegrass, provided almost as much cover. As with Younkin's (1972) species and fertilizer trials, the two native grasses were relatively unsuccessful, providing at most 25 to 35 per cent cover on their best dates. Cottongrass was absent from all but the second last seeding date where a few seedlings were observed. None was seen in 1971 (Wein 1971a:14). Once again, flowering decreased with lateness of planting except for Climax timothy and Leo birdsfoot trefoil.

TABLE 12 COVER RATING[a] AND HEIGHT[b] FOR SPECIES SOWN ON DIFFERENT DATES THROUGHOUT THE SUMMER OF 1971 NEAR PRUDHOE BAY, ALASKA. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR FOUR REPLICATES OF EACH SEEDING DATE, UNLESS OTHERWISE NOTED. SAMPLED AUGUST 11,1972.

| Species | | SEEDING DATE | | | |
|---|---|---|---|---|---|
| | | June 20 | July 8 | August 18 | August 28 |
| | | Cover Rating and Height (cm) | | | |
| Arctared creeping red fescue | C[a] | 3.0±0.4 | 1.2±0.2 | 1.2±0.2 | 2.5±0.3 |
| | H[b] | 10.0±0.7 | 3.1±0.8 | 7.0±0.9 | 6.8±0.8 |
| Nugget Kentucky bluegrass | C | 2.8±1.0 | 1.0±0.0 | 1.2±0.2 | 2.9±0.2 |
| | H | 5.0±0.9 | 1.0±0.0 | 3.5±0.6 | 3.5±0.3 |
| Climax timothy | C | 1.5±0.3 | 0.5±0.5[c] | 2.5±0.3 | 2.8±0.2 |
| | H | 7.5±0.6 | 0.5±0.5 | 8.2±0.8 | 8.2±0.6 |
| Sawki Russian wildrye | C | 1.0±0.0 | 1.0±0.0[c] | 0.8±0.2 | 1.5±0.3 |
| | H | 8.3±0.3 | 4.0±1.0 | 4.5±1.6 | 6.5±1.0 |
| Aurora alsike clover | C | 1.0±0.0 | 0.8±0.2 | 1.0±0.0 | 1.5±0.3 |
| | H | 1.5±0.3 | 0.8±0.2 | 1.0±0.0 | 1.0±0.0 |
| Tall arcticgrass | C | 1.5±0.3 | 1.0±0.0 | 1.0±0.0 | 1.2±0.2 |
| | H | 7.0±1.1 | 3.0±0.4 | 3.8±0.2 | 4.5±0.3 |
| Frontier reed canarygrass | C | 0.5±0.3 | 0.8±0.2 | 1.2±0.2 | 2.2±0.2 |
| | H | 3.2±1.9 | 2.8±1.1 | 5.5±0.6 | 8.3±1.3 |
| Bluejoint | C | 1.2±0.2 | 1.0±0.0 | 1.0±0.0 | 1.8±0.2 |
| | H | 3.2±0.8 | 2.0±0.4 | 2.5±0.6 | 5.2±0.9 |
| Fairway crested wheatgrass | C | 0.2±0.2 | 0.8±0.2 | 2.2±0.5 | 2.5±0.3 |
| | H | 3.3±3.3 | 2.5±1.2 | 13.8±1.0 | 13.8±1.6 |
| Falcata alfalfa | C | 0.8±0.2 | 1.0±0.0 | 0.8±0.2 | 1.5±0.3 |
| | H | 1.8±0.6 | 1.0±0.0 | 2.0±0.7 | 6.5±1.0 |
| Leo birdsfoot trefoil | C | 1.0±0.0 | 1.0±0.0 | 0.5±0.3 | 1.0±0.0 |
| | H | 1.8±0.2 | 1.5±0.3 | 0.5±0.3 | 1.5±0.5 |
| Cottongrass | C | 0.8±0.2 | 0.5±0.3 | 0 | 0.2±0.2 |
| | H | 0.8±0.2 | 0.5±0.3 | 0 | 0.2±0.2 |

a C: Cover rating classes (based on amount of rows covered by plants): 0 - 0%; 1 - 1 to 10% 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%.

b H - Height of plant. The plants at this site are of low stature (compared to those of Inuvik,Table 11 and Norman Wells, Table 10) and have no flowers because of heavy grazing by caribou

c Two of the four replicates were washed out.

SEEDING DATE

| Species | First Sum[b] | First Rank[d] | Second Sum[b] | Second Rank[d] | Third Sum[c] | Third Rank[d] | Fourth Sum[b] | Fourth Rank[d] | Fifth Sum[b] | Fifth Rank[d] | Combined[e] Sum[b] | Combined[e] Rank[d] | Mean[f] Sum | Mean[f] Rank | Overall[g] Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arctared creeping red fescue | 5.5x | 1.5 | 4.5x | 1 | 3x | 1 | 7 | 2 | 9.5 | 2 | 3.5x | 1 | 1.94 | 1.42 | 1 |
| Nugget Kentucky bluegrass | 5.5x | 1.5 | 7.5x | 2 | 3.5x | 2 | 8 | 3 | 11 | 3 | 6x | 2 | 2.44 | 2.25 | 2 |
| Climax timothy | 19.5 | 7 | 25y | 10 | 11.5 | 5.5 | 6.5x | 1 | 4.5x | 1 | 10 | 3 | 4.53 | 4.58 | 3 |
| Sawki Russian wildrye | 18 | 6 | 12 | 3 | 6.5x | 3 | 22.5 | 8 | 22y | 8 | 17.5 | 4 | 5.79 | 5.33 | 4 |
| Aurora alsike clover | 17 | 5 | 23.5y | 9 | 11.5 | 5.5 | 19 | 6 | 17 | 6 | 20 | 6 | 6.38 | 6.25 | 6 |
| Tall arcticgrass | 16 | 3 | 17 | 5 | 10.5 | 4 | 20y | 7 | 27y | 9 | 20.5 | 7 | 6.53 | 5.83 | 6 |
| Frontier reed canarygrass | 21.5 | 8 | 22y | 7 | 16y | 8 | 17.5 | 4 | 16 | 5 | 18.5 | 5 | 6.56 | 6.17 | 6 |
| Bluejoint | 16.5 | 4 | 16.5 | 4 | 17y | 9 | 23y | 9 | 19.5y | 7 | 21.5 | 8 | 6.71 | 6.83 | 8 |
| Fairway crested wheatgrass | 31y | 11 | 29y | 11 | 18.5y | 10.5 | 18.5 | 5 | 13.5 | 4 | 23y | 9 | 7.85 | 8.42 | 9 |
| Falcata alfalfa | 27y | 10 | 18.5y | 6 | 15.5y | 7 | 29y | 11 | 29y | 10.5 | 28.5y | 10 | 8.68 | 9.08 | 10 |
| Leo birdsfoot trefoil | 23 | 9 | 23y | 8 | 18.5y | 10.5 | 27.5y | 10 | 29y | 10.5 | 29y | 11 | 8.82 | 9.83 | 11 |
| Cottongrass | 33.5y | 12 | 35.5y | 12 | 24y | 12 | 35.5y | 12 | 36y | 12 | 36y | 12 | 11.79 | 12.00 | 12 |

a All rankings shown such that 1 is best species (based on cover rating) and 12 is worst. If species are equal, each is given the average of all the ranks involved.
b Total of the individual rankings, based on cover rating, of each species at each of 3 sites. Norman Wells, Inuvik, Prudhoe Bay
c As for b except that only 2 sites, Norman Wells and Inuvik, were seeded.
d Rank based on sum for that date.
e Obtained from total cover rating over all dates at each site.
f Mean Sum: Total of all sums shown divided by the 17 values which gave them.
Mean Rank: Mean of the 5 date and combined ranks given.
g Overall rank based on both Mean Sum and Mean Rank
x Mean cover rating on this date was 3.0 (ie > 40%) over all sites.
y Mean cover rating on this date 1.7 (ie < 15%) over all sites.

TABLE 13 COVER RANKINGS[a] FOR SPECIES BASED UPON INDIVIDUAL AND COMBINED SEEDING DATES FOR PLOTS ESTABLISHED IN 1971 AT THREE SITES. THESE RESULTS ARE BASED ON THE MEAN COVER NOTING OF EACH SPECIES IN FOUR REPLICATES AT EACH SITE AS PRESENTED IN TABLES 10, 11, AND 12

The mid-August sampling data from Prudhoe Bay are given in Table 12. Seeding was on a gravel-topped peaty soil. Arctared creeping red fescue and Nugget Kentucky bluegrass were the only species to have appreciable (greater than 40 per cent) cover for the first and last seeding dates. All other species, for most planting dates, had poor success (less than 20 per cent cover) in establishing. Here, too, cottongrass seedlings were seen for the first time. As mentioned previously, grazing by caribou prevented the various species from flowering.

Table 13 contains the rankings (based on cover) of the species tested in this experiment for each seeding date over all three sites. The best species - mean cover greater than 50 per cent - and the worst - mean cover less than 15 per cent are indicated for each date and for all dates combined. Arctared creeping red fescue and Nugget Kentucky bluegrass were best overall and for the first three seeding dates. For the last two dates, Climax timothy was best. The least successful species overall were cottongrass, Leo birdsfoot trefoil, Falcata alfalfa and Fairway crested wheatgrass. Only three species were rated 'worst' for the first seeding date. They were the wheatgrass, alfalfa and cottongrass. All other seeding dates had 5, 6 or 7 such classed species (see Table 13).

Studies at the agricultural research station in Palmer, Alaska (61.5$^{o}$N) examined the effect of different planting dates on the winter survival, forage yield and seed production of varieties of winter rye (Klebesadel 1969a) and bromegrass and timothy (Klebesadel 1970). Rye yields were lower with later planting date. Winter kill differed among the timothy and bromegrass varieties tested but, of those surviving the best, seed and forage yield were usually greatest for the earliest planting (May 23, 1964) and had sharp declines after late June to early July plantings. No seed was produced in the same year after a mid-July planting. The second year after planting, bromegrasses produced little or no seed after late July sowing. Engmo timothy, however, produced some seed in the second year after July and August plantings but the amounts decreased with the later seeding dates. Forage yield in the second year after planting was approximately constant for Engmo timothy (4.5 to 6.5 metric tons of dry matter per hectare) for all planting dates up to mid-July. For three brome varieties yields were much greater (9 to 14 metric tons/hectare) for May and June planting dates but dropped sharply throughout July seeding dates. Herbage yield was low or nonexistent for all varieties after July seeding.

TABLE 14 MEAN TOTAL COVER OF GRASSES AND LEGUMES SEEDED IN MID-JUNE 1971 WITH DIFFERENT AMOUNTS OF NURSE CROP (OATS AND/OR RYE) OVER LOW GRAVEL AND ORGANIC SOIL BERMS AT PRUDHOE BAY, ALASKA. DATA ARE MEANS ± STANDARD ERROR FOR THREE 20 x 50 CM GUADRATS FOR 2 REPLICATES ON GRAVEL AND 3 ON ORGANIC SOIL (SAMPLED AUGUST, 11, 1972)

| Treatment[a] | | SOIL TYPE Gravel | Organic |
|---|---|---|---|
| | | Cover (%) | |
| Control | G[b] | 1.3±0.4 | 3.8±0.5[c] |
| | L[b] | 0.2±0.1 | 0.6±0.2[c] |
| 40 Oats + 30 Rye | G | 1.5±0.8 | 5.0±1.0[c] |
| | L | 0.2±0.1 | 0.8±0.2[c] |
| 40 Oats | G | 1.3±0.9 | 2.3±0.3[c] |
| | L | 0.2±0.1 | 0.7±0.1[c] |
| 80 Oats | G | 1.0±0.0 | 3.7±0.8 |
| | L | 0.4±0.1 | 0.3±0.1 |
| 120 Oats | G | 1.3±0.9 | 3.3±0.3[c] |
| | L | 0.2±0.1 | 0.8±0.1[c] |
| 30 Rye | G | 1.2±0.1 | 4.2±1.0 |
| | L | 0.5±0.2 | 0.3±0.1 |
| 60 Rye | G | 0.4±0.1 | 5.0±0.8 |
| | L | 0.2±0.1 | 0.7±0.2 |
| 120 Rye | G | 0.7±0.1 | 3.8±0.6 |
| | L | 0.3±0.1 | 0.5±0.1 |

[a] Treatments: Control - No nurse crop. Numbers (i.e. 30, 40, etc.) refer to amount of nurse crop sown in Kg/ha

[b] G - Grasses: Arctared creeping red fescue and climax timothy
L - Legumes: Aurora alsike clover and Leo birdsfoot trefoil

[c] One replicate was lost when the berm slumped

These patterns were similar to those observed in the present study at Norman Wells, Inuvik and Prudhoe Bay. Flowering, noted earlier, decreased with later planting date. And, if height and cover may be taken as rough measures of production, such production was noted to decrease in this study with later seeding.

Nurse Crop Competition

The results from the cereal nurse crop study established at Prudhoe Bay in 1971 are presented in Table 14. Two soil types had been seeded, a low (1.5 m) gravel berm and a low peat fill berm. By August 1972, there was little plant cover. No differences in grass and legume cover were detected between controls and plots seeded with cereal nurse crop. Despite the low cover, organic soil consistently had some 3.5x as much grass cover and 2x as much legume cover as the gravel. Grasses were much more abundant than legumes on both soil type.

Dead seedlings were seen at all sites in 1972. Live seedlings did not appear vigorous in either year. Most of those counted in 1972 appeared to have germinated that year. None of the legume seedlings appeared to have overwintered. Some grass seedlings, 2 of 7 at Norman Wells and 4 of 14 at Prudhoe Bay, may have overwintered successfully and could be two years old. They were distinguished from seedlings deemed to have germinated in the current year by their somewhat larger stature and by two or three dead basal leaves. However, they were still short plants with 4 to 6 leaves and no seed heads.

Some 10,000 seeds of each species were sown at each site (about 11 kg/la for all species combined). Thus, germination in the first year was approximately 0.4 per cent at Norman Wells and 1.2 per cent at Inuvik and Prudhoe for the grasses. Of these, over-wintering was 8 per cent at Norman Wells, 0 per cent at Inuvik and 5 per cent at Prudhoe Bay (or 0.03 per cent, 0 per cent and 0.06 per cent per unit area respectively of the original amounts sown). Successful establishment of these species in native vegetation thus far appears unlikely, as has been found in the northern U.S.S.R. (Dorogostajskaja 1972).

Two sets of plots were sown at both Inuvik (Table 15) and Norman Wells (Table 16), one in 1971, the other in 1972. Sowing of the cereal nurse crop did not result in an increase in the cover of the sown perennial species. In the high application rates, it actually resulted in a decrease in cover.

TABLE 15 MEAN COVER OF SOWN GRASSES AND COLONIZING NATIVE SPECIES GROWING IN PLOTS SEEDED WITH DIFFERENT AMOUNTS OF ANNUAL NURSE CROP (OATS AND/OR RYE) AT INUVIK, N.W.T. PLOTS WERE ESTABLISHED IN EARLY JUNE IN BOTH 1971 AND 1972. DATA ARE MEANS ± STANDARD ERROR FOR THREE 20 x 50 CM QUADRATS FOR EACH OF THREE REPLICATES PER TREATMENT (SAMPLED AUGUST 25, 1972)

| | | Treatment[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Year Sown | Control | Oats + Rye | 40 Oats | 80 Oats | 160 Oats | 30 Rye | 60 Rye | 120 Rye |
| Oats[s] | 1972 | - | 5.4±1.2 | 4.3±0.7 | 3.3±0.9 | 5.0±1.3 | - | - | - |
| | 1971 | - | 0 | 0 | 0 | 0 | - | - | - |
| Rye[s] | 1972 | - | 0.8±0.4 | - | - | - | 1.3±0.7 | 1.6±0.5 | 3.3±0.9 |
| | 1971 | - | 16.0±6.4 | - | - | - | 13.6±2.6 | 14.8±5.9 | 13.4±5.8 |
| Arctared creeping red fescue[s] | 1972 | 1.5±0.2 | 1.0±0.2 | 1.4±0.3 | 1.4±0.2 | 1.9±0.6 | 1.5±0.3 | 2.2±0.7 | 1.2±0.2 |
| | 1971 | 9.7±0.8 | 2.3±0.5 | 10.4±1.0 | 9.7±1.5 | 10.7±0.8 | 3.8±0.3 | 3.1±0.5 | 2.2±0.4 |
| Climax timothy[s] | 1972 | 2.1±0.5 | 1.2±0.5 | 1.8±0.7 | 1.3±0.3 | 1.0±0.5 | 2.6±0.7 | 2.8±0.8 | 1.9±0.5 |
| | 1971 | 3.6±0.7 | 2.7±0.4 | 3.6±0.6 | 4.0±1.2 | 322±0.5 | 2.1±0.4 | 2.4±0.4 | 2.3±0.5 |
| Aurora alsike clover[s] | 1972 | 3.9±0.9 | 2.0±0.7 | 2.3±0.5 | 1.7±0.3 | 3.1±0.9 | 3.7±0.8 | 3.0±0.8 | 1.8±0.4 |
| | 1971 | 3.6±0.7 | 0.4±0.2 | 4.3±0.6 | 1.9±0.4 | 4.3±0.6 | 0.9±0.3 | 1.9±0.3 | 0.3±0.1 |
| Leo birdsfoot trefoil[s] | 1972 | 0.9±0.3 | 0.4±0.2 | 0.3±0.2 | 0.7±0.3 | 0.4±0.1 | 1.2±0.3 | 0.5±0.1 | 0.2±0.1 |
| | 1971 | 1.9±0.2 | 0.5±0.2 | 2.4±0.3 | 1.3±0.3 | 2.1±0.3 | 1.1±0.1 | 0.9±0.2 | 0.3±0.1 |
| Horsetails[n] | 1972 | 0 | 1.2±0.9 | 2.2±1.2 | 4.2±2.0 | 0.3±0.3 | 0 | 0 | 2.8±1.4 |
| Willows[n] | 1971 | 1.1±0.5 | 1.5±0.7 | 3.8±2.2 | 1.7±0.5 | 2.0±0.9 | 0.4±0.3 | 1.8±0.7 | 1.1±0.8 |
| Fireweed[n] | 1971 | 6.1±1.1 | 4.9±1.5 | 2.2±0.8 | 5.0±2.5 | 3.4±1.0 | 4.7±1.0 | 2.2±0.8 | 3.7±1.3 |
| Grasses[n] | 1971 | 0.8±0.4 | 1.5±0.9 | 0.2±0.2 | 0.6±0.3 | 0.5±0.3 | 3.7±0.9 | 2.1±0.9 | 2.3±1.1 |
| Marsh fleabane[n] | 1971 | 1.2±0.3 | 1.5±0.5 | 0.9±0.4 | 0.3±0.2 | 0.5±0.2 | 1.3±0.5 | 0.6±0.3 | 0.4±0.2 |
| Mosses[n] | 1971 | 0.8±0.4 | 8.2±2.2 | 9.4±2.1 | 7.3±2.2 | 8.5±2.7 | 11.5±2.3 | 6.3±1.4 | 5.7±1.8 |

a Treatments: Control - No nurse crop. Numbers (i.e., 30, 40, etc.) refer to amount of nurse crop sown in kg/ha (≈lb/ac). Oats + rye treatment was 40 oats and 30 rye (i.e., equal numbers of seeds for each cereal).

n Native species growing in the plots

s Species which were sown.

TABLE 16 MEAN COVER OF SOWN GRASSES AND LEGUMES AND COLONIZING NATIVE SPECIES GROWING IN PLOTS SEEDED WITH DIFFERENT AMOUNTS OF ANNUAL NURSE CROP (OATS AND/OR RYE) AT NORMAN WELLS, N.W.T. PLOTS WERE ESTABLISHED, IN EARLY JUNE IN BOTH 1971 AND 1972. DATA ARE MEANS ± STANDARD ERROR FOR THREE 20 x 50 CM QUADRATS FOR EACH OF THREE REPLICATES PER TREATMENT (SAMPLED, AUGUST 31, 1972)

| | | Treatment[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Year Sown | Control | Oats + Rye | 40 Oats | 80 Oats | 160 Oats | 30 Rye | 60 Rye | 120 Rye |
| Oats[s] | 1972 | - | 19.5±3.0 | 13.9±1.2 | 37.0±2.6 | 26.7±5.0 | - | - | - |
| | 1971 | - | 0 | 0.4±0.4 | 0 | 0 | - | - | - |
| Rye[s] | 1972 | - | 24.1±3.7 | - | - | - | 29.3±4.1 | 55.7±4.2 | 69.7±4.6 |
| | 1971 | - | 0 | - | - | -- | 0 | 0.7±0.4 | 1.3±0.7 |
| Arctared creeping red fescue[s] | 1972 | 5.5±1.0 | 3.1±0.6 | 3.1±0.6 | 6.0±0.5 | 2.5±0.5 | 3.8±1.0 | 2.9±0.4 | 2.2±0.4 |
| | 1971 | 17.1±1.8 | 11.3±2.0 | 15.4±2.5 | 13.1±2.5 | 9.1±1.8 | 12.1±2.3 | 11.1±2.8 | 11.1±1.7 |
| Climax timothy[s] | 1972 | 13.2±1.0 | 5.2±0.6 | 4.3±0.6 | 7.5±0.9 | 3.1±0.6 | 9.2±1.0 | 8.1±1.0 | 7.5±1.0 |
| | 1971 | 3.8±1.2 | 1.3±0.3 | 3.8±0.9 | 2.9±0.8 | 3.6±1.2 | 2.7±0.8 | 1.0±0.3 | 2.9±0.6 |
| Aurora alsike clover[s] | 1972 | 5.8±0.8 | 4.1±0.7 | 4.9±0.7 | 7.1±0.8 | 4.3±0.5 | 6.5±0.9 | 6.3±0.8 | 2.9±0.5 |
| | 1971 | 1.8±0.6 | 0.5±0.1 | 1.5±0.2 | 1.7±0.7 | 0.7±0.2 | 1.1±0.2 | 0.8±0.5 | 1.7±0.8 |
| Leo birdsfoot trefoil | 1972 | 2.5±0.3 | 1.4±0.2 | 1.6±0.2 | 3.1±0.3 | 2.1±0.4 | 2.0±0.2 | 1.9±0.3 | 1.0±0.2 |
| | 1971 | 0.9±0.3 | 0.2±0.1 | 1.3±0.5 | 0.9±0.3 | 0.5±0.2 | 0.5±0.2 | 0.5±0.2 | 1.4±0.6 |
| Horsetails[n] | 1972 | 2.4±0.7 | 1.1±0.3 | 3.0±1.0 | 0.8±0.4 | 3.5±1.0 | 2.1±1.0 | 1.0±0.4 | 1.1±0.7 |
| | 1971 | 3.6±0.9 | 4.2±1.0 | 4.3±0.8 | 3.8±0.8 | 3.9±0.8 | 3.4±0.4 | 3.8±0.6 | 4.0±0.6 |
| Willows[n] | 1972 | 0 | 1.3±0.9 | 0.1±0.1 | 0 | 0.1±0.1 | 0 | 0 | 0 |
| | 1971 | 0.4±0.3 | 1.7±1.0 | 0.5±0.3 | 0.5±0.2 | 0.8±0.4 | 1.0±0.4 | 1.0±0.4 | 2.2±0.7 |
| Sedges[n] | 1972 | 0 | 0.1±0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1971 | 0 | 2.1±1.0 | 0.5±0.2 | 1.3±0.7 | 0.7±0.4 | 2.2±0.8 | 2.3±1.3 | 0.2±0.2 |
| Mosses[n] | 1972 | 7.0±1.4 | 5.7±1.3 | 6.3±1.6 | 4.7±2.9 | 8.8±2.9 | 8.0±1.8 | 1.7±0.8 | 0 |
| | 1971 | 31.9±5.6 | 39.3±6.2 | 32.3±4.9 | 41.5±7.2 | 34.0±8.7 | 42.8±6.9 | 33.0±8.0 | 35.3±5.0 |
| Other species[bn] | 1972 | 0 | 0.5±0.5 | 0 | 0 | 0.9±0.4 | 0 | 0 | 0 |
| | 1971 | 0.7±0.4 | 1.3±1.0 | 0.9±0.3 | 0.5±0.2 | 0.8±0.4 | 1.5±0.5 | 0.8±0.4 | 1.6±0.6 |

a Treatments: Control - No nurse crop. Numbers (i.e. 30, 40, etc.) refer to amount of nurse crop sown in kg/ha (≈lb/ac).
Oat + rye treatment was 40 oats + 30 rye (i.e. equal number of seeds for each cereal).

b Other species included *Epilobium angustifolium* (fireweed), *Potentilla fruticosa* (Shrubby cinquefoil), *Vaccinium uliginosum* (blueberry); *Ledum groenlandicum* (Labrador tea); *Rosa acicularis* (rose); *Arctostaphylos rubra* (bearberry); *Arctagrostis latifolia* (tall arcticgrass).

n Native species growing in the plots

s Species which were sown

TABLE 17 LIST OF INTRODUCED AGRONOMIC SPECIES (LEGUMES - L; GRASSES - G) SOWN IN UNDISTURBED NATURAL COMMUNITIES AT NORMAN WELLS AND INUVIK, N.W.T. AND PRUDHOE BAY, ALASKA.

| Common Name | g or l | Scientific Name |
|---|---|---|
| Fairway crested wheatgrass | g | *Agropyron cristatum* |
| Sawki Russian wildrye | g | *Elymus junceus* |
| Frontier reed canarygrass | g | *Phalaris arundinacea* |
| Climax timothy | g | *Phleum pratense* |
| Nugget Kentucky bluegrass | g | *Poa pratensis* |
| Arctared creeping red fescue | g | *Festuca rubra* |
| Boreal creeping red fescue | g | *Festuca rubra* |
| Meadow foxtail | g | *Alopecurus pratensis* |
| Falcata alfalfa | l | *Medicago sativa* |
| Leo birdsfoot trefoil | l | *Lotus corniculatus* |
| Aurora alsike clover | l | *Trifolium hybridum* |

TABLE 18 TOTAL NUMBER OF LIVE SEEDLINGS OF THREE LEGUME (L) AND EIGHT GRASS (G) SPECIES GROWING IN AUGUST 1971 AND AUGUST 1972 IN UNDISTURBED NATURAL COMMUNITIES AT THREE STUDY SITES. DATA OBTAINED FROM 80 1/10 $M^2$ QUADRATE AT EACH SITE. APPROXIMATELY 10,000 SEEDS OF EACH SPECIES WERE SOWN AT EACH SITE IN JUNE 1971.

| Site Location | Community Type | Number of Live Seedlings: Legumes 1971 | Legumes 1972 | Grasses 1971 | Grasses 1972 |
|---|---|---|---|---|---|
| Norman Wells, N.W.T. | Black Spruce Forest | 25 | 4 | 24 | 7[a] |
| Inuvik, N.W.T. | Open Black Spruce Forest | 8 | 0 | 75 | 16 |
| Prudhoe Bay, Alaska | Wet Sedge Tundra Polygons | 158 | 33 | 79 | 14[a] |

a Includes possible two-year old seedlings: 2 of 7 at Norman Wells and 4 of 14 at Prudhoe Bay. All other seedlings had germinated during the year they were counted.

Plant cover was generally higher at Norman Wells than at Inuvik, for both the sown and naturally colonizing species. The native colonizers were approximately 50 per cent of the total plant cover on the 1971 plots at Inuvik and 67 per cent at Norman Wells. Mosses made up a large proportion at both sites. Fireweed was also prominent at Inuvik, no doubt because of the large seed source on the adjacent hillsides around the town as a result of the fire in August 1968.

Both oats and rye flowered at Norman Wells and Inuvik in 1972. Oats were up to 1m tall and rye reached 1.5m. The viability of this seed is presented later. Few seed heads of the four perennial species were seen in the 1971 plots and only Climax timothy and Aurora alsike clover flowered occasionally in the 1972 plots.

### Survival of Agronomic Seed Sown in Native Plant Communities

The 11 agronomic species sown in mid-June 1971 in undisturbed plant communities at Norman Wells (closed black spruce forest), Inuvik (open black spruce forest) and Prudhoe Bay (wet sedge tundra polygons) are listed in Table 17. The number of live seedlings found in 80 quadrats (20x50 cm) at each site in both years is given in Table 18. Seedlings could not be distinguished to species in either year because of their lack of development. Thus, they were only counted as grasses or legumes.

## New Experiments

### Winter Road Revegetation Study

Three seed mixes (see previous Methods section for composition of each) were sown in early June on portions of a winter road at Tuktoyaktuk and a 1971-72 winter seismic line and bladed trails at Norman Wells. Two soil types, a relatively lightly disturbed (only peat exposed) and a more heavily disturbed (mineral clayey sand exposed), were seeded at Tuktoyaktuk.

The native forbs, fireweed and marsh fleabane, could easily be distinguished from the grasses and are listed separately (Table 19). The latter, however are grouped because they were usually no more than seedlings and thus difficult to identify. At Norman Wells, three soil-community types were seeded, exposed wet peat through tamarack-sedge wetlands, exposed mesic to dry peat of black spruce-shrub-heath forest and exposed moist mineral soil of the forest. Timothy, along with the native forbs, could be distinguished at this site (Table 20). The other grasses were grouped as their individual cover was quite low.

| Species | | Organic: Nat 0 | Organic: Nat 100 | Organic: Agr 0 | Organic: Agr 100 | Organic: All 0 | Organic: All 100 | Mineral: Nat 0 | Mineral: Nat 100 | Mineral: Agr 0 | Mineral: Agr 100 | Mineral: All 0 | Mineral: All 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SOIL TYPE[a] / Treatment[b] — Cover (%), Number of Plants/m$^2$ and Height (cm) | | | | | | | | | | | |
| Marsh fleabane | C[c] | 0.2±0.05 | 0.5±0.1 | N.A.[f] | N.A.[f] | 0.2±0.05 | 0.6±0.2 | 0.1±0.1 | 1.1±0.3 | N.A. | N.A. | 0.2±0.05 | 0.6±0.2 |
| | N[d] | 7±3 | 14±4 | | | 8±4 | 16±5 | 9±7 | 19±6 | | | 8±4 | 16±5 |
| | H[e] | 0.2±0.1 | 0.6±0.1 | | | 0.2±0.1 | 0.6±0.1 | 0.1±0.04 | 0.9±0.1 | | | 0.2±0.1 | 0.6±0.1 |
| Fireweed | C | 0.2±0.1 | 1.3±0.2 | | | 0.2±0.1 | 1.2±0.3 | 0.1±0.1 | 1.7±0.6 | | | 0.2±0.1 | 1.2±0.3 |
| | N | 18±8 | 56±15 | | | 8±2 | 52±18 | 6±3 | 83±33 | | | 8±2 | 52±18 |
| | H | 0.2±0.1 | 1.0±0.1 | | | 0.3±0.1 | 1.0±0.1 | 0.1±0.1 | 1.0±0.2 | | | 0.3±0.1 | 1.0±0.1 |
| Grasses | C | 0.5±0.0 | 0.5±0.02 | 0.6±0.05 | 1.6±0.16 | 0.6±0.03 | 1.2±0.1 | 0.5±0.3 | 0.6±0.1 | 0.9±0.1 | 1.7±0.1 | 0.7±0.1 | 1.3±0.1 |
| | N | 45±5 | 57±7 | 140±22 | 179±24 | 96±13 | 144±20 | 76±17 | 78±10 | 210±29 | 163±20 | 180±43 | 124±16 |
| | H | 1.6±0.1 | 3.1±0.2 | 2.7±0.2 | 6.6±0.4 | 2.3±0.2 | 6.0±0.4 | 1.4±0.2 | 3.1±0.3 | 3.2±0.3 | 7.8±0.3 | 2.7±0.3 | 6.9±0.7 |

a Organic soil - Nine replicates (Reps 1 to 9 in Appendix A, Fig.20) were established on exposed peat of the winter road proper passing through dwarf shrub-heath plant communities. Mineral Soil-Four replicates (Reps 10 to 13, Appendix A, Fig.20 ) were established on a clayey sand heavily disturbed area off the road.

b Treatments: Nat-Native seed mix: tall arcticgrass, bluejoint, fireweed, marsh fleabane; Agr-Agronomic seed mix: Arctared creeping red fescue, Canada bluegrass, Climax timothy, Orchardgrass; all-Total mix of all 8 species listed; 0-No fertilizer; 100-100kg/ha of both elemental N and P.

c C - Cover    d N - Number of plants/m$^2$    e - H - Height to longest leaf or top of seed head

f N.A. - not sown

TABLE 19 PLANT COVER, DENSITY AND HEIGHT FOR THE THREE SEED MIXES AND TWO FERTILIZER LEVELS SOWN ON TWO SOIL TYPES ON A WINTER ROAD NEAR TUKTOYAKTUK, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR 45 QUADRATS (50 x 20 cm) ON ORGANIC SOIL AND 20 QUADRATS OF MINERAL SOIL. SAMPLED AUGUST 19, 1972

| | | SOIL TYPE[a] Treatment[b] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wet Organic | | | | | | Dry Organic | | | | | |
| | | Nat 0 | Nat 100 | Agr 0 | Agr 100 | All 0 | All 100 | Nat 0 | Nat 100 | Agr 0 | Agr 100 | All 0 | All 100 |
| | | Cover (%), Number of Plants/m$^2$ and Height (cm) | | | | | | | | | | | |
| Marsh fleabane | C[c] | 1.1±0.5 | 3.8±0.7 | | | 0.5±0.1 | 0.9±0.3 | 0.1±0.03 | 2.2±0.5 | | | 0.1±0.16 | 0.7±0.2 |
| | N[d] | 11±4 | 30±10 | | | 8±2 | 6±2 | 4±2 | 18±5 | | | 2±2 | 8±2 |
| | H[e] | 0.7±0.2 | 1.4±0.3 | | | 0.4±0.1 | 1.3±0.5 | 0.1±0.03 | 1.1±0.2 | | | 0.1±0.1 | 0.9±0.4 |
| Fireweed | C | 0.8±0.2 | 6.1±1.0 | N.A. | | 1.0±0.3 | 4.3±1.5 | 0.2±0.06 | 8.4±1.1 | N.A. | | 0.1±0.05 | 5.7±0.8 |
| | N | 45±13 | 118±20 | | | 28±8 | 54±13 | 11±5 | 114±16 | | | 9±5 | 79±11 |
| | H | 0.4±0.1 | 2.5±0.6 | | | 0.4±0.1 | 3.0±1.1 | 0.2±0.06 | 3.8±0.6 | | | 0.1±0.05 | 3.8±0.7 |
| Climax timothy | C | | | 3.0±0.4 | 7.4±1.1 | 2.9±0.3 | 3.7±0.4 | | | 2.6±0.5 | 10.5±1.0 | 1.1±0.2 | 4.8±0.4 |
| | N | N.A. | | 115±14 | 143±16 | 76±8 | 74±7 | N.A. | | 101±14 | 163±15 | 63±11 | 108±9 |
| | H | | | 5.5±0.6 | 21.7±2.8 | 8.5±1.0 | 15.2±3.4 | | | 5.5±0.8 | 30.1±3.0 | 3.0±0.3 | 17.5±1.7 |
| Other Grasses | C | 1.3±0.2 | 2.2±0.2 | 1.9±0.2 | 3.2±0.3 | 1.6±0.2 | 2.8±0.3 | 0.7±0.1 | 1.5±0.2 | 1.5±0.2 | 2.9±0.3 | 1.1±0.1 | 2.5±0.3 |
| | N | 95±9 | 141±17 | 196±23 | 172±28 | 149±19 | 144±15 | 56±11 | 76±9 | 188±31 | 133±14 | 111±17 | 108±11 |
| | H | 1.8±0.2 | 4.3±0.3 | 3.4±0.4 | 6.6±0.6 | 3.0±0.3 | 5.3±0.4 | 2.0±0.3 | 5.0±0.6 | 2.5±0.2 | 6.7±0.6 | 2.3±0.2 | 5.3±0.3 |

a Wet Organic Soil - Six replicates (Nos. 6, 9, 15 to 18, Appendix A, Fig. 19) were established on exposed wet peat through areas of tamarack-sedge; Dry Organic Soil - Six replicates (Nos. 3, 7, 8, 10, 11, 14, Appendix A, Fig. 19) were established on exposed mesic peat through areas of black spruce-shrubs-heath forest. Mineral Soil - Six replicates (Nos. 1, 2, 4, 5, 12, 13, Appendix A, Fig. 19) were established on exposed mineral soil through areas of black spruce-shrub-heath forest.

b Treatments: Nat - Native seed mix; tall arcticgrass, bluejoint, fireweed, marsh fleabane; Agr - Agronomic seed mix: Arctared creeping red fescue, Canada bluegrass, Climax timothy, Orchardgrass; All Total mix of all 8 species listed; 0 - No fertilizer; 100-100kg/ha of both elemental N and P.

c C - Cover   d N - Number of plants/m$^2$   e H - Height to longest leaf tip or top of seed head   f N.A. - not sown

TABLE 20 PLANT COVER, DENSITY AND HEIGHT FOR THE THREE SEED MIXES AND TWO FERTILIZERS SOWN ON THREE COMMUNITY-SOIL TYPES ON A 1971-72 WINTER SEISMIC LINE AND BLADED TRAILS TO SIMULATE A WINTER ROAD NEAR NORMAN WELLS, N.W.T. DATA ARE GIVEN AS MEANS ± STANDARD ERROR FOR 30 QUADRATS (50 x 20 cm) ON EACH OF A WET ORGANIC SOIL, A DRY ORGANIC SOIL AND A MINERAL SOIL. SAMPLED AUGUST 30, 1972

| | | Soil Type | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mineral | | | | | |
| | | Treatment | | | | | |
| | | Nat 0 | Nat 100 | Agr 0 | Agr 100 | All 0 | All 100 |
| | | Cover (%), Number of Plants/m$^2$ and Height (cm) | | | | | |
| Marsh fleabane | C[c] | 1.2±0.5 | 6.8±1.0 | | | 0.6±0.3 | 3.0±0.6 |
| | N[d] | 14±5 | 43±7 | | | 8±4 | 20±3 |
| | H[e] | 0.7±0.2 | 3.7±0.5 | N.A. | | 0.3±0.1 | 2.6±0.5 |
| Fireweed | C | 0.3±0.1 | 7.1±1.7 | | | 0.1±0.1 | 6.3±1.0 |
| | N | 20±8 | 99±20 | | | 4±2 | 79±10 |
| | H | 0.3±0.1 | 4.8±1.4 | | | 0.1±0.1 | 7.0±1.1 |
| Climax timothy | C | | | 2.8±0.4 | 11.3±0.8 | 2.8±0.5 | 7.9±0.6 |
| | N | N.A. | | 117±12 | 151±10 | 81±9 | 103±6 |
| | H | | | 7.5±1.0 | 37.5±2.9 | 7.2±0.8 | 34.8±2.6 |
| Other Grasses | C | 1.1±0.1 | 2.1±0.3 | 1.3±0.1 | 4.3±0.4 | 1.6±0.2 | 3.6±0.6 |
| | N | 119±22 | 103±11 | 134±21 | 108±13 | 130±15 | 103±9 |
| | H | 2.4±0.2 | 5.2±0.4 | 2.9±0.2 | 10.6±0.8 | 3.1±0.3 | 9.1±0.8 |

TABLE 20 (CONTINUED)

Fertilizer resulted in approximately a three-fold increase in plant cover and height and often a doubling of seedling establishment for all seed mixes and in all soil types at both sites. Plant cover at Norman Wells averaged some five times that at Tuktoyaktuk for individual species, seed mixes and soil types. Approximately 1.5x as many plants had become established. These were also much larger and taller at the more southerly latitude of Norman Wells with its generally warmer climate and longer growing season. Seed heads of Climax timothy were quite abundant on the fertilized plots at Norman Wells.

Fireweed was the most successful species of the native mix, although grass seedlings were numerous. Marsh fleabane was more abundant in the wetter replicates at both sites. Climax timothy was the most successful of the grasses in the agronomic mix. Differences between the seed mixes used could not be detected in this first year but may become apparent in subsequent years.

## Viability of Seed Produced in Test Plots

Seed from the 1970 species trials at Inuvik and the 1971 plots at Norman Wells, Inuvik and Tuktoyaktuk was collected for testing of viability from species whose seed heads appeared to be mature. The principal species examined were the two agronomically developed northern grasses Arctared creeping red fescue and Nugget Kentucky bluegrass (by far the most successful species in all plots), and the two native grasses bluejoint and tall arcticgrass. Also tested were Slender wheatgrass, Frontier reed canarygrass, Meadow foxtail, Fairway crested wheatgrass and Aurora alsike clover.

At first, seeds were moistened and placed directly in a germination chamber at 20$^{o}$C and continuous light. Examination of the data (Table 21) and knowing that some of the species tested require a pre-chilling for proper germination, led to a second experiment. Seeds were moistened, pre-chilled at 40$^{o}$C for 10 days and germinated as before (20$^{o}$C, continuous light) (Table 22).

The Association of Official Seed Analysts (1970) lists the following species and varieties of those examined in the field plots as having a pre-chilling requirement: Nugget Kentucky bluegrass, Arctared creeping red fescue, Fairway crested wheatgrass and Slender wheatgrass. Total germination was approximately 24 per cent without and 52 per cent with pre-chilling. This increase was largely due to the very significant increase of Nugget Kentucky bluegrass from virtually no germination (mean 2.3 per cent) without pre-chilling to an average germination of 44.1 per cent after pre-chilling. Arctared creeping red fescue had relatively

| Species Tested | 1970 Inuvik Organic C | 1970 Inuvik Organic $N_1$ | 1970 Inuvik Organic $P_1$ | 1970 Inuvik Organic $L_1$ | 1970 Inuvik Organic $N_1P_1$ | 1970 Inuvik Organic $N_1P_1L_1$ | 1970 Inuvik Min C | 1971 Organic Inuvik $N_1P_1$ | 1971 Organic Inuvik $N_1P_2$ | 1971 Organic Inuvik $P_2$ | 1971 Organic Tuk $N_1P_1$ | 1971 Organic Tuk $N_1P_2$ | 1971 Mineral Inuvik C | 1971 Mineral Inuvik $N_1P_1$ | 1971 Mineral Inuvik $N_1P_2$ | 1971 Mineral Inuvik $P_2$ | 1971 Mineral Tuk $N_1P_1$ | 1971 Mineral Tuk $N_1P_2$ | 1971 Norman Wells Berm Hot | 1971 Norman Wells Berm Cold |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Germination | | | | | | | | | | | | | | | | | | | |
| Arctared creeping red fescue | +[z] | a[z] | 62.7 | 42.7 | 30.7 | 33.3 | 81.3 | 81.3 | 13.3 | + | a | a | + | 69.3 | 77.3 | 29.3 | a | a | 34.7 | 34.7 |
| Nugget Kentucky bluegrass | + | a | 4.0 | a | 2.7 | 1.3 | 0 | 1.3 | 4.0 | 0 | 2.7 | 0 | + | 4.0 | 2.7 | 0 | 0 | 0 | 6.7 | 6.7 |
| Slender wheatgrass | 4.0 | 13.3 | 6.7 | 9.3 | 8.0 | 6.7 | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Bluejoint | -[z] | - | - | - | - | - | - | 26.7 | 58.7 | 46.7 | + | + | 50.7 | + | 52.0 | 49.3 | a | + | - | - |
| Tall arcticgrass | - | - | - | - | - | - | - | 28.0 | 28.0 | 14.7 | a | a | + | + | 18.7 | a | + | 34.7 | - | - |
| Frontier reed canarygrass | a | a | a | a | a | a | a | a | a | a | a | a | a | 2.7 | 0 | a | a | a | 1.3 | 0 |
| Meadow foxtail | a | a | + | a | + | + | + | - | - | - | - | - | - | - | - | - | - | - | 1.3 | 1.3 |
| Fairway crested wheatgrass | - | - | - | - | - | - | - | a | a | a | a | a | a | a | a | a | a | a | 4.0 | a |
| Aurora alsike clover | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 | + |

x Tuk - Tuktoyaktuk; Min - Mineral Soil; Organic - Organic Soil; Berm - Mineral Soil Fill Berm over pipe.

y C - Control (No fertilizer); N - Nitrogen fertilizer; P - Phosphorus fertilizer; L - Lime fertilizer; 1-100kg/ha of element; 2-200kg/ha of element; Hot - pipe in berm maintained at 65°F; Cold - pipe at 15°F.

z - Species not sown in this experiment.

a No or virtually no seed heads produced in this treatment.

\+ Seed heads were produced but not collected for germination tests because the seed did not appear mature.

Either a or + applied also to treatments missing from this table (eg. 1970 Inuvik Mineral, $N_1$, $P_1$, $L_1$, etc., 1971 Mineral Tuk C, $P_2$, etc.)

TABLE 21 GERMINATION PERCENTAGES FOR SEED COLLECTED FROM SOME OF THE SPECIES TRIALS ESTABLISHED AT INUVIK IN 1970 AND AT NORMAN WELLS, INUVIK AND TUKTOYAKTUK IN 1971. DATA ARE PERCENT GERMINATING AT 20°C AND CONTINUOUS LIGHT FOR 75 SEEDS FOR EACH TREATMENT

| Species Tested | 1970 Inuvik Organic C | 1970 Inuvik Organic $N_1$ | 1970 Inuvik Organic $P_1$ | 1970 Inuvik Organic $L_1$ | 1970 Inuvik Organic $N_1P_1$ | 1970 Inuvik Organic $N_1P_1L_1$ | 1970 Inuvik Min C | 1971 Organic Inuvik $N_1P_1$ | 1971 Organic Inuvik $N_1P_2$ | 1971 Organic Inuvik $P_2$ | 1971 Organic Tuk $N_1P_1$ | 1971 Organic Tuk $N_1P_2$ | 1971 Mineral Inuvik C | 1971 Mineral Inuvik $N_1P_1$ | 1971 Mineral Inuvik $N_1P_2$ | 1971 Mineral Inuvik $P_2$ | 1971 Mineral Tuk $N_1P_1$ | 1971 Mineral Tuk $N_1P_2$ | Norman Wells Berm Hot | Norman Wells Berm Cold |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Germination | | | | | | | | | | | | | | | | | | | |
| Arctared creeping red fescue | + | a | 73.3 | 37.3 | 33.3 | 74.7 | 72.0 | 73.3 | 8.0 | + | a | a | + | 90.7 | 81.3 | 65.3 | a | a | 62.0* | 53.3 |
| Nugget Kentucky bluegrass | + | a | 52.0 | a | 52.0 | 58.0* | 52.0 | 46.7 | 66.7 | 50.7 | 8.0 | 8.0 | + | 70.7 | 73.3 | 80.0 | 6.7 | 20.0 | 26.0* | 42.7 |
| Slender wheatgrass | 45.3 | 58.7 | 49.3 | 32.0 | 60.0 | 33.3 | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Bluejoint | - | - | - | - | - | - | - | 89.3 | 81.3 | 81.3 | + | + | 77.3 | + | 89.3 | 97.3 | a | + | - | - |
| Tall arcticgrass | - | - | - | - | - | - | - | 88.0 | 72.0 | 82.7 | a | a | + | + | 76.0 | a | + | 58.7 | - | - |
| Frontier reed canarygrass | a | a | a | a | a | a | a | a | a | a | a | a | a | 62.7 | 30.0* | a | a | a | 18.7 | 0 |
| Meadow foxtail | a | a | + | a | + | + | + | - | - | - | - | - | - | - | - | - | - | - | 40.0 | 30.0* |
| Fairway crested wheatgrass | - | - | - | - | - | - | - | a | a | a | a | a | a | a | a | a | a | a | 0 | a |
| Aurora alsike clover | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 |

x Tuk - Tuktoyaktuk; Min - Mineral Soil; Organic - Organic Soil; Berm - Mineral Soil fill berm over pipe.
y C - Control (No Fertilizer); N - Nitrogen; P - Phosphorus; L - Lime; 1-100 kg/ha of element; 2-200 kg/ha of element; Hot - pipe in berm maintained at 65°F; cold - pipe at 15°F.
\- Species not sown in this experiment
a No or virtually no seed heads produced in this experiment
\+ Seed heads were produced but not collected for germination tests because the seed did not appear mature. Either a or + applied to treatments missing from this table (e.g. 1970 Inuvik Mineral $N_1$, $P_1$, $L_1$, etc.)
* Based on only 50 seeds.

TABLE 22 GERMINATION PERCENTAGES FOR SEED COLLECTED IN 1972 FROM SOME OF THE SPECIES TRIALS ESTABLISHED AT INUVIK IN 1970 AND AT NORMAN WELLS, INUVIK AND TYKTOYAKTUK IN 1971. DATA ARE PERCENT GERMINATING AT 20°C AND CONTINUOUS LIGHT FOR 75 SEEDS PER TREATMENT FOLLOWING 10 DAYS OF PRECHILLING AT 4°C.

high germination (49.2 per cent average) without pre-chilling but after treatment, germination increased to 60.4 per cent. Slender wheatgrass, Frontier reed canarygrass and Meadow foxtail had very low germination without the pre-treatment (8.0, 1.0 and 1.3 per cent respectively) but were significantly increased to 46.2, 27.9 and 35.6 per cent after the chilling. Aurora alsike clover did not germinate in either experiment. Fairway crested wheatgrass had a 4 per cent germination without chilling but none after chilling.

Younkin collected seed from the 1970 established plots in the fall of 1971. He found high (90 to 100 per cent) germination for Engmo timothy. The bluegrasses, Canon Canada and Nugget Kentucky, had low germination (4 to 30 per cent). These tests were all without pre-chilling. Arctared creeping red fescue did not flower in 1971. Rye had been planted in 1970 at Inuvik. It produced seed which was collected in 1971 and subsequently germinated (98 per cent). Rye sown in 1971 at Norman Wells in the nurse crop competition study similarly had high germination (93 per cent). Oats, in the same experiment, had only a 63 per cent germination.

Both native grasses seeded in the plots also seemed to be affected by pre-chilling. Calamagrostis canadensis increased significantly from mean germination of 47 per cent to 86 per cent, while germination of Arctagrostis latifolia jumped from 25 per cent to 75 per cent. As part of his autecological studies of Calamagrostis and Arctagrostis, Younkin (1973) has conducted extensive germination experiments with these two species. Seed collected from plants naturally colonizing disturbed areas and from plants in undisturbed communities usually had germination of 80 to 90 per cent without pre-chilling. These values were much greater than those observed for these species seeded in the plots and germinated without pre-chilling but were comparable to those with pre-chilling.

Low percentage germination (as in Table 21) may be due to several factors. Some species require a pre-treatment such as pre-chilling or scarification before they will germinate. Other species may not germinate because the seed may not have been mature when tested. Thus, in germination experiments a negative result does not imply inability to produce viable seed, just as presence of seed heads does not assure seed viability. While absence of seed heads is often the surest sign of inability to produce seed because of physiological or nutritional limitation, other external factors such as grazing by herbivores may prevent maximum seed production.

## Plant Collections of Inhabited Areas

The plant identifications have not yet been completed. Preliminary examinations of the specimens have not revealed any new introductions into the Northwest Territories, but two possible range extensions have been noted from the vicinity of the Norman Wells dump and rock quarry. They are *Corydalis sempervirens* (L.) Pers. (pale corydalis) and *Geranium bicknellii* Britt. (cranesbill). Neither species is included in Cody (1960) although the latter species has previously been found at Fort Simpson (Cody 1961).

Other species typical of disturbed or 'waste' areas included *Hordeum jubatum* (squirreltail grass), *Linum lewisii* (flax), *Dracocephalum parviflorum* (dragonhead), *Capsella bursa-pastoris* (shepherd's purse), and *Chenopodium capitatum* (strawberry blite).

In the U.S.S.R., investigations have been carried out into the invasion of weedy species into tundra areas. Dorogostajskaja (1972) lists 298 such species. Few succeed in invading established plant communities. Most are maintained in cultivated areas, settlements and other areas disturbed by man's activities.

# INTEGRATION

## Natural Plant Recolonization After Disturbance

The study of plant invasion into northern habitats disturbed either by man's activities or naturally, as in mudflows, has accelerated recently. Most plant community changes in arctic regions have been in the relative abundance of the species present and not by a change in species composition (Muller 1952, Churchill and Hanson 1958). However, there exists an assemblage of species which is successful in colonizing exposed soil (Hernandez 1972). The grasses, *Calamagrostis canadensis* (bluejoint), *Arctagrostis latifolia* (tall arcticgrass) and *Poa lanata*, are the most common pioneers of exposed mineral soil in mesic upland sites of the Tuktoyaktuk Peninsula region and are also common in the natural upland dwarf shrub-heath community (Younkin 1973). In moist areas, *Eriophorum vaginatum* (cottongrass) appears to be stimulated both vegetatively and in flower production by disturbance which does not eliminate it (Hernandez 1972). *Arctophila fulva* (pendent grass) and *Carex aquatilis* typically colonize wet lowland sites spreading by rhizomatous expansion. In northwestern Alaska, silty mud outwashes were colonized by *Senecio congestus* (marsh fleabane) (Hok, 1969). Lambert (1972) examined tundra mudflows west of Aklavik, N.W.T. which were initially colonized by *Senecio congestus* and

*Eriophorum scheuchzeri*. Subsequently, grasses (bluejoint, tall arcticgrass), *Equisetum arvense* (horsetail) and *Petasites frigidus* (sweet coltsfoot) became established. Once a turf has been re-established, any islands of natural vegetation (dwarf shrub-heath-herb-moss clumps) which survived the mud-slide gradually expanded and replaced the colonizing community. Thus, secondary succession on these sites is a two-step process. The first is a colonizing element of unknown duration and the second the re-establishment of the natural community. Dorogostajskaja (1972) stated that grasses are typical of newly-created habitats in the arctic regions of the U.S.S.R.

In the Arctic Islands, lush sedge meadows, which form a major food base for large herbivores (musk-oxen, caribou), are very susceptible to summer damage and recover much more slowly than in the western Canadian low arctic (Babb 1972).

Forested and tall shrub communities in the Mackenzie Delta suffer much greater initial damage from winter seismic lines than do tundra communities because of the removal of trees. Recovery of this vegetation, however, is more rapid. Plant cover increased from 1.4 per cent in the first year to 22 per cent in the second and to more than 60 per cent in the third year after disturbance. Much of the growth was from roots and rhizomes but some colonizing species seeded in (Hernandez 1972). No spruce seedlings were found.

Disturbances of the tundra are less detrimental in winter than in summer. At least 50 per cent of the natural community remains intact as do the roots and rhizomes which send up new shoots in subsequent years (Hernandez 1972).

Wet lowland sedge communities, which are sensitive to as little as one pass of a vehicle in summer (Bellamy *et al*. 1971), are much less damaged in winter. Regrowth is mostly from underground stems (rhizomes). Few species seem able to seed into extremely wet areas and thus maintenance of the peat layer with intact rhizomes if of great importance (Hernandez 1972).

## Characteristics of Agronomically Developed and Native Grasses

Several varieties of agronomically selected grasses have proven successful when seeded into disturbed areas of the tundra and northern boreal forest--this is not suprising in view of their northern origins. Native species which are natural colonizers of disturbed northern areas are also potentially useful in revegetation. The characteristics of these grasses are discussed and, where possible, compared in this section. Elliott and Bolton (1970) provide some background information for all the varieties of grasses and legumes licensed for sale in Canada.

The two most successful agronomically - developed varieties in these and other arctic revegetation studies have been Arctared creeping red fescue and Nugget Kentucky bluegrass. Both were developed at the Agricultural Research Station in Palmer, Alaska. Nugget Kentucky bluegrass originated from a selection at Hope, Alaska (Hodgson et al. 1971) and Arctared creeping red fescue from the Matanuska River valley (W.W. Mitchell, personal communication).

Klebesadel et al. (1964) grew seed lots of Poa pratensis (Kentucky bluegrass) and Festuca rubra (creeping red fescue) from locations in North America and Europe near Palmer, Alaska from August 1960 to May 1962. Among them were the collections which became the varieties Nugget and Arctared respectively. All seed lots survived the mild winter of 1960-61 with no winter-kill. The severe winter of 1961-62, however, resulted in heavy mortality for all lots except those from north of 60° latitude. (Alaska and Iceland). This winter killing has been attributed to incomplete preparation for winter dormancy (Klebesadel 1971). When southern varieties were given a proper night period, they had much better survival but still produced few flowers. Reduction or interruption of the night period for the subarctic-adapted varieties greatly reduced heading in the subsequent year. Lengthening this period did not significantly decrease flower production. Hodgson (1966) showed that many Alaskan grasses initiate floral development in the fall. The results from these studies are of great importance for breeding programmes and maximum seed production since they reveal the importance of the proper light and dark period in the fall for maximum winter survival and flower production (Klebesadel 1971).

Of the two native species which have been tested in this study, bluejoint (Calamagrostis canadensis) forms extensive grasslands in the coastal region of south central Alaska, grasslands which decrease as one goes north. (Mitchell and Evans 1966). Klebesadel and Laughlin (1964) discuss their utilization for forage. Klebesadel (1965) found that nitrogen increased crude protein content and all fertilizer treatments decreased dry matter production. Yield was decreased with two yearly harvests when no fertilizer, or nitrogen alone, was used. Laughlin (1969) confirmed that annual complete fertilizer application (nitrogen, phosphorus and potassium) is required for continued annual use of bluejoint stands. Klebesadel et al. (1962) discuss seed characteristics and techniques for threshing of bluejoint.

Investigations into the agronomic characteristics (Klebesadel 1969b) and autecology (Younkin 1973) of tall arcticgrass (Arctagrostis latifolia) have recently begun. The species is slow to establish in an area and seems susceptible to competition from other species during the seedling stage (Klebesadel 1969b). However, once established, it grows quickly and can flower by the second year (Younkin 1973).

Tall arcticgrass has a more northerly distribution than bluejoint. The former is native only north of 50° (Klebesadel 1969b) while the latter is at its northern limit near Tuktoyaktuk (Younkin 1973). Bluejoint, thus, is better adapted to the boreal forest; tall arcticgrass to the tundra. The former rarely produces flower heads in native tundra communities while tall arcticgrass does. Its percent germination decreases with decrease in temperature, but all arcticgrass maintains a high percent germination down to 5°C (41°F). Both below and above ground production of bluejoint are more affected by cold soils than is that of tall arcticgrass (Younkin 1973).

Younkin (1973) also grew Arctared creeping red fescue, Kall orchardgrass (which grows well in the first year), bluejoint and tall arcticgrass in cold soils. Root production was greatly decreased with the agronomically developed varieties in comparison to the native species.

Revegetation and Soil Energy Budget

The re-establishment of vegetation on disturbed areas in permafrost regions has been expected to accelerate the restoration of a more natural soil energy budget and thus lead to stabilization and re-establishment of pre-disturbance permafrost conditions. An energy budget study was carried out by Haag (1973) this past summer at Norman Wells and Tuktoyaktuk. Part of it involved monitoring the revegetation plots seeded in 1970, 1971, and 1972 on various winter roads at Tuktoyaktuk, as well as similarly aged areas of the road which were being recolonized naturally. The following results, figure and discussion are from Haag and Bliss (1973). Figure 2 compares the albedo of the different aged reseeded and naturally revegetating areas. These had a plant cover of up to 50 per cent but little associated litter for the older sites. Albedo increased from a low of 8 per cent on the road itself to within 1 per cent of control in the three year old reseeded plots and to within 3 per cent in the three years-old areas naturally revegetating. Thaw which penetrated 56 cm in the winter road itself, was 52 cm deep under the naturally revegetating areas, and 50 cm under the plots. Control areas thawed only 36 cm. Thus, the decrease in absorbed radiation which occurs as vegetation becomes established, results in a slight decrease in thaw depth. But this is not as great as expected were vegetation alone a critical factor in controlling thaw depth.

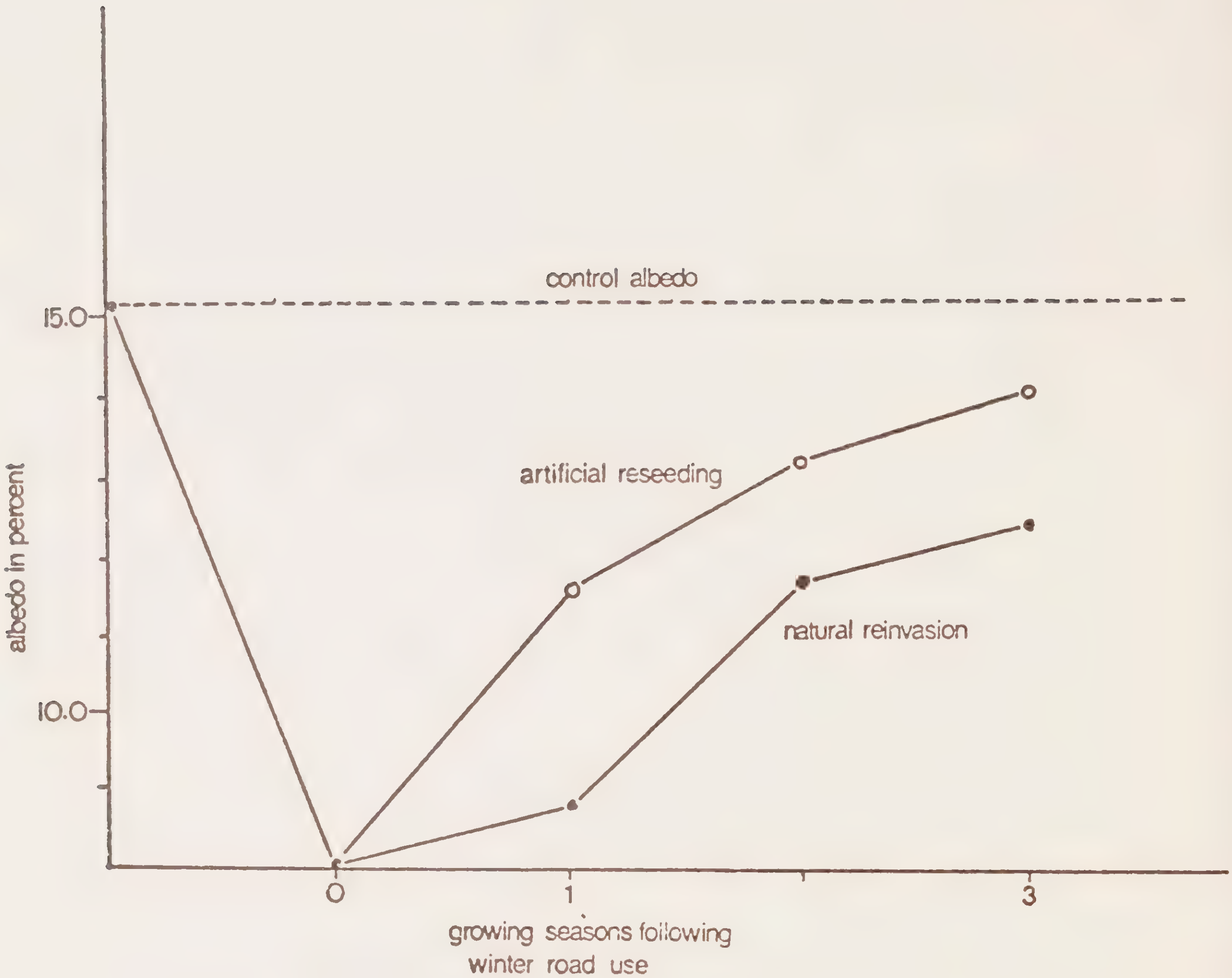


Fig. 2 Comparison of albedo change under artificial reseeding and natural plant reinvasion on a winter road. (from Haag and Bliss 1973)

The similarity of thaw depth in the disturbed areas, probably resulted from the lack of litter accumulation. With plant establishment, net radiation decreases but the lack of litter or organic mat enables the soil heat flux component to remain large. Only with the re-establishment of an organic mat can the depth of thaw be reduced. Reseeding may shorten the period required to develop the organic mat but by how much and how appreciably is currently unknown. Thus, immediate (1 to 3 years) restoration of a natural soil energy budget does not appear possible with reseeding in the tundra.

In the warmer boreal forest, however, reseeding programmes may be more effective in restoring soil energy budgets. More litter was produced and accumulated under the most successful species in test plots at the Sans Sault Rapids Test Facility north of Norman Wells. Soil energy flow measurements indicated a more normal subsurface energy balance by the second year after reseeding and refertilizing (D.L. Dabbs, Northern Engineering Services Ltd., Calgary; personal communication).

Conclusions

(1) Three species have consistently proven most successful in tundra areas and are among the most successful in producing an excellent ground cover in forested areas by the second year. They are (a) Arctared and (b) Boreal creeping red fescue and (c) Nugget Kentucky bluegrass. (W.W. Mitchell; personal communication and Neubauer (1972); however, found that after 4 years Arctared was the best species by far (90 to 95 per cent cover) while both Nugget Kentucky bluegrass and Boreal creeping red fescue began to show some winter kill.

(2) More species become established, overwinter successfully and grow well in the second year as one goes south into the boreal forest. These species included Meadow foxtail, Slender wheatgrass and Engmo timothy.

(3) The legumes Aurora alsike clover and Falcata alfalfa have some limited success in warm exposures from Inuvik south. They could prove beneficial in fixing soil nitrogen.

(4) Species which have proven unsuccessful over one or two years in most tests are Greenleaf wheatgrass, Fairway crested wheatgrass, Streambank wheatgrass, Polar bromegrass, Sawki Russian wildrye, Kall orchardgrass and Leo birdsfoot trefoil on both organic and mineral soils and Imperial and Frontier reed canarygrass on organic soil.

(5) The native grasses, bluejoint (<u>Calamagrostis canadensis</u>) and tall arcticgrass (<u>Arctagrostic latifolia</u>) establish more slowly than the 3 best species on test plots. However, they are excellent natural colonizers of disturbed areas in the northern boreal forest and tundra, with tall arcticgrass being better adapted to tundra and cold soils of forest areas, and bluejoint to the boreal forest (Younkin 1973).

(6) Gravel is the most difficult type of material on which to establish a plant cover. This was most evident when comparing Wein's (1971a) species trials over the hot oil loop at Inuvik and hot gas pipe at Norman Wells. Other tests showed these two locations not to be markedly different climatically and in species response. However, the hot oil loop, covered with gravel, had virtually no plant cover while the hot gas pipe, covered with mineral soil, has the best plant cover and earliest spring growth of all test plots examined in this study.

(7) When moist, mineral soil and peat are better able than gravel to support plant growth, with mineral soil often supporting the greater variety of species, taller plants and the greater cover.

(8) Low seeding rates (5.5 to 11kg/ha) used in this study generally resulted in 30 to 50 per cent plant cover for the best species by the second year over low (1.5m) berms. Higher seeding rates (16.5 to 55kg/ha) in other studies resulted in greater plant establishment and cover in the first and subsequent years. (W.W. Mitchell, personal communication - for Prudhoe Bay; D.L. Dabbs, personal communication - for Sans Sault Rapids).

(9) Seeding is best done in early spring or late fall to take advantage of moist soil since much of the northern portion of the pipeline route is in areas of low precipitation and especially low summer rainfall.

(10) Fertilizer is required for good plant establishment. The effects of fertilizer appear to be lost by the second year, especially in the northern boreal forest but somewhat less so in the tundra. Re-fertilization in the second year has proved extremely beneficial in enhancing plant growth in both the tundra (W.W. Mitchell, personal communication) and boreal forest (D.L. Dabbs, personal communication). Rates of 112kg/ha of elemental N and 224 kg/ha of elemental P are best in promoting growth. Application of potassium (56 to 112 kg/ha acre of elemental K) also appears useful.

(11) Most agronomic species tested produced viable seed in the year after sowing, especially where fertilized, Flowering at Prudhoe Bay is possible (Neubauer 1972; W.W. Mitchell, personal communication) although it was not seen in the present study because of grazing by caribou.

(12) Introduction of agronomic seed into native undisturbed plant communities is unlikely. Some species may maintain themselves in 'waste' places and other disturbed areas.

(13) Reseeding does not prevent melt-out and possible subsidence of disturbed areas because plant growth is not fast enough to restore an organic mat in the first year. It can, however, reduce soil erosion. Side slopes in forest areas may be stabilized by the planting of willow and alder cuttings (D.L. Dabbs, personal communication).

(14) Re-establishment of vegetation, naturally or by reseeding does not appear able to restore soil energy budgets in tundra areas, within the first three years and possibly not for longer. This is due to (a) great alteration or removal by disturbance of the surficial organic mat and (b) slow production and accumulation of litter in these areas (Haag and Bliss 1973). However, in the warmer boreal forest, reseeding programmes may be more effective in restoring soil energy budgets as more litter is produced (D.L. Dabbs, personal communication).

(15) Reseeded areas were grazed by caribou in the summer and fall and used by small rodents (voles, mice lemmings) in winter. Arctic hares also grazed on some of the plots. Birds fed on seed.

## NEEDS FOR FURTHER STUDY

(1) The transferability of the data from small test plots to large areas is not known. Similar results are likely, however. This can easily be tested by reseeding areas such as rig sites.

(2) Revegetation studies have not been established in the southern half of the pipeline route. This area, however, has a better climate and is more similar to populated southern areas. Thus, the more traditional knowledge, such as that from the Canadian Department of Agriculture Research Station at Beaverlodge, Alberta, is likely to be applicable. Elliott (1971) lists the species under test at Beaverlodge and their

success over time. Goff (1969)* discussed the preliminary results on erosion control research methods, among them seeding, nurse crops and mulches, in the Swan Hills area of Alberta.

(3) The long term effects of reseeding in northern areas are not known. Data are available for only three summers and two winters, certainly not sufficiently long to determine the effects of extreme conditions on the successful species. Both Nugget Kentucky bluegrass and Arctared creeping red fescue may be susceptible to snowmold (Hodgson *et al*, 1971; Smith, 1972; Mitchell personal communication).

(4) The extent and pattern of natural recolonization of seeded and fertilized areas is little know. Mosses increased greatly in fertilized disturbed areas, whether the areas were seeded or not (see Table 16, this report for Norman Wells; D.L. Dabbs, personal communication, for Sans Sault; Neubauer (1972) for Prudhoe Bay). The three main invaders on the 1970 established plots at Inuvik were fireweed (*Epilobium angustifolium*), marsh fleabane (*Senecio congestus*) and tansy mustard (*Descuriania sophioides*) along with some bluejoint (*Calamagrostis canadensis*) and tall arcticgrass (*Arctagrostis latifolia*). More plants were established on mineral soil than organic. Only fireweed responded to fertilizer. Phosphorus-containing treatments had more plants than non-phosphorus treatments (3x on mineral soil; 2x on organic).

(5) The effects of fertilizer on adjacent water bodies is little known. Since most northern lakes are low in nutrients, fertilizer could prove beneficial.

(6) Reseeding of the entire route with only a few species could lead to the establishment of a relatively uniform expanse of vegetation. This could also result if only a few species prove successful in reseeding. Thus a seed mix including native species is encouraged to lessen the danger of 'crop failure' under adverse conditions (i.e. harsh climate or disease).

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* The final report of this project will be presented at the N.R.C. Hydrology, Symposium No. 9, in May 1973, at the University of Alberta. A paper will be published as part of the proceedings and will include results from revegetation trials (R.C. Davis, Acting Head, Research Section, Department of Lands and Forests, Government of Alberta, Edmonton; personal communication).

(7) The ultimate effects of successful plant establishment on animal behaviour are unknown. Birds have eaten broadcast seed and animals have grazed established test plots. If seeded and fertilized areas prove more palatable or nutritious than the native vegetation and if animals are selective in their grazing, attraction to and grazing along a reseeded line could occur. The effect of such animal activities could markedly reduce the effectiveness of a revegetation programme. This area of plant-animal interactions is probably one of the most important and least understood.

## PRELIMINARY IMPLICATIONS AND RECOMMENDATIONS

The following revegetation practices are presented, based on the current state of knowledge and recognizing that they are preliminary and tentative.

### Extremely Dry Areas

Experience has shown these to be most difficult to revegetate, either by reseeding or naturally. Natural plant cover is low on gravelly eskers. Once removed, it will be difficult to replace.

### Wet Tundra Areas

Little growth and establishment of the species tested thus far is likely in wet areas. Here, however, regrowth from undisturbed roots and rhizomes of native species is possible. If construction on these areas is restricted to times when they are frozen, damage will be minimized. Maintenance of the subsurface drainage and replacement of the organic mat (not necessarily as an intact unit but as blocks of sod or tussocks) after construction may result in regrowth from roots and rhizomes. Roots and rhizomes may thus, regrow. Such a technique is probably equally applicable to muskeg and bog areas in the boreal forest.

### Slope Stabilization

The most promising technique, thus far, appears to be the transplanting of willow and alder cuttings in addition to a heavy seeding of grasses with some mulching.

### Mesic Tundra Areas

Until further and more detailed information on the proportion and characteristics of the various plant communities present along the pipeline route becomes available, the following is recommended for tundra areas, recognizing that there are a variety of communities.

Plant establishment and growth are best on mineral soil and poorest on a dry peat mat. Thus, mineral subsurface soil appears best in areas where its exposure and resultant increased soil conductivity will not lead to melt of subsurface ice. The replacement of much of the organic mat is not recommended if one is going to reseed. However, if reseeding is not done, then the mat must be replaced for growth from root and rhizomes. This technique would be most successful in moister areas.

The following (Table 23) are the proposed seed mixes for the upland dwarf shrub-heath of the eastern Mackenzie Delta region and possibly, cottongrass tussock tundra areas along the Arctic coast and alpine areas.

Table 23. Preliminary seed mixes proposed for mesic tundra area.

| | Weight of seed (lb/ac) | |
|---|---|---|
| | Mix of best species | Diverse Mix |
| Arctared creeping red fescue | 13 | 10 |
| Nugget Kentucky bluegrass | 13 | 10 |
| Tall arcticgrass | 8 | 8 |
| Bluejoint | 8 | 8 |
| Slender wheatgrass | 4 | $3\frac{1}{2}$ |
| Frontier reed canarygrass | 4 | $3\frac{1}{2}$ |
| Engmo timothy | 0 | $3\frac{1}{2}$ |
| Meadow foxtail | 0 | $3\frac{1}{2}$ |

Nurse crop: If quick growth is desired, 10 lb/ac winter rye may be useful. Frontier reed canarygrass may also act as a nurse crop.

Fertilizer: 100 lb/ac of elemental N and 200 lb/ac of elemental P seem best. Some K would also be useful, possibly in the range of 50 to 100 lb/ac of element.

The proposed mixes differ only in one having two more species which overall are less successful but which increase the diversity possible. Utilization of native seed will be dependent on obtaining and developing sufficient quantities.

## Northern Boreal Forest

Recommendations for boreal forest areas must await release of the second and subsequent years' results from other studies in boreal forest areas (Sans Sault; and Interior Alaska). However, the following suggestions seem applicable:

(1) The annual cereal nurse crop may be omitted since perennial grasses such as Frontier reed canarygrass, Engmo timothy, Meadow foxtail and Slender wheatgrass should grow quickly in the first year.

(2) Tall arcticgrass can probably be omitted for all areas except the northern boreal forest where permafrost is present since it is best adapted in tundra and cold soil areas. Bluejoint, should be useful in the boreal forest.

(3) Boreal creeping red fescue could possibly be substituted for Arctared in these areas.

(4) Legumes, such as Aurora alsike clover and Falcata alfalfa, may prove beneficial in these warmer areas, especially if innoculated with the proper bacteria for nitrogen fixation.

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## SUMMARY

Data are presented from August 1972 analyses for a variety of reseeding plots established at Norman Wells, Inuvik and Tuktoyaktuk, N.W.T. and Prudhoe Bay, Alaska in the early summers of 1970, 1971 and 1972. The four sites are in the northern boreal forest, boreal forest to tundra transition, upland dwarf shrub-heath tundra and coastal wet sedge polygon tundra respectively.

Over the years, 27 species have been tested in plots. They included: 16 agronomically developed perennial grass varieties, 2 native grasses, 1 native sedge, 3 annual cereals, 3 legumes and 2 native forbs. Boreal and Arctared creeping red fescue and Nugget Kentucky bluegrass were either the best, or among the best, in all plots. The native grasses, bluejoint (*Calamagrostis canadensis*) and tall arcticgrass (*Arctagrostis latifolia*), proved moderately successful in seeding tests. They are prominent colonizers of disturbed tundra and northern boreal forest areas. Tall arcticgrass is best adapted to tundra and cold soil conditions and bluejoint does best in the boreal forest. More species, including Meadow foxtail, Slender wheatgrass and Engmo timothy, became established, overwintered successfully and grew in subsequent years. The legumes Aurora alsike clover and Leo birdsfoot trefoil were only successful in warm soils.

Eight different fertilizer treatments were tested over the years of this study. Those containing phosphorus, either alone or in combination, proved better for supporting growth. Those in which nitrogen was also present seemed best overall, with 100 kg/ha of elemental nitrogen and 200 kg/ha of elemental phosphorus the best. The effect of fertilizer was often lost by the second or third year. Other studies have shown that re-fertilization in the year after seeding was very beneficial in promoting plant growth.

Gravel substrates supported little, if any, plant growth. Peat and mineral soil supported a greater plant cover, with mineral soil the best.

Low seeding rates (55 to 11 kg/ha) generally resulted in 30 to 60 per cent plant cover for the best species by the second year. Higher seeding rates in other studies have resulted in greater plant cover (75 to 95 per cent for the best species).

Seeding in late fall seemed equivalent to early spring seeding. However, seeding during the summer reduced establishment, cover, height and flowering of most species, partly because of the lack of available soil water.

Agronomic species produced flowering heads with viable seed in their second or third year at all sites except Prudhoe Bay, where grazing by caribou throughout the summer prevented flowering. Seed of these same species did not establish or over winter significantly in native undisturbed plant communities.

Reseeding does not prevent subsidence. Re-establishment of plant cover, either naturally or be reseeding, did not restore the natural soil energy budget on a winter road through an upland tundra dwarf shrub-heath community within the first three years. However, reseeding in the boreal forest may be more effective, as more litter is produced.

Tentative and preliminary revegetation techniques and seed mixes are proposed.

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ADDENDUM

Since the text of this report was written, summary reports from two additional Alaskan studies have become available. Their major results and relevance to the present report are summarized and discussed below.

Summary of McCown (1972)

McCown (1972) examined the effects of a buried heated line on the success of revegetation attempts near Fairbanks, Alaska from the spring of 1970 through the winter of 1971-72. A 1.2 m diameter pipe buried with 1.2m of overburden passed through three zones of vegetation: (a) a paper birch community with relatively warm, well-drained soils, (b) a spruce community with more restricted drainage and colder, wetter soils and (c) the transition zone between (a) and (b). The internal temperature of the pipe was maintained at 60 to 65$^{o}$C. As a result, soil temperatures 30 cm below the surface and 3 to 4m on either side of the pipe were 30$^{o}$C in summer and 5 to 10 C in winter. Air temperatures over the pipe were no different than over adjacent cleared but unheated areas. Snow accumulation was negligible in a 2 to 4m wide band over the pipe.

Seven introduced grasses (Manchar bromegrass, Boreal creeping red fescue, Nugget Kentucky bluegrass, Engmo timothy, Crested and Siberian wheatgrasses and Perennial ryegrass), four native herbaceous dicotyledons and four native shrub and tree species were tested with and without fertilizer on both heated and unheated areas. Mulches were also examined.

Plants growing on heated areas were accelerated in germination, spring growth, flowering and seed set when compared to those on adjacent unheated areas. Fertilizer effects were greatest on unheated soils, implying that the effect of warm soils was to increase nutrient availability. Soil analyses and other laboratory studies supported the contention that nutrients are limiting in cold soils. The best species (based on biomass) over the pipe were Manchar bromegrass, Boreal creeping red fescue and Engmo timothy. Nugget Kentucky bluegrass was slightly less successful than these three species and proved susceptible to snowmold in unheated areas. The wheatgrasses had little biomass. Boreal creeping red fescue was superior in the second year, even in unfertilized, unheated spruce areas. Seed production was greater in the second year. Mulching reduced plant established and growth because of nutrient deficiencies. Re-fertilizing in the second year increased growth.

Plant survival in the second winter was greatly affected by grazing by microtene rodents. These were most active on the thawed soils over the pipe and selectively grazed herbaceous dicots up to 100 per cent. Grasses were locally heavily utilized and woody species relatively untouched except for occasional girdling. Although grazing appeared similar in all zones on the test site, the "fertilized plots did seem to have heavier damage than the control plots" (McCown 1972:60).

Invasion of native species on to the test site was generally limited to cleared but unplanted areas. Some species seeded in; others sprouted from rootstocks. Seeded areas were not noticeably invaded until heavy grazing eliminated the established species. McCown (1972) thus concluded that replacement of seeded species by natives would seem unlikely if the density of sown species were maintained at the levels of his study.

Summary of Van Cleve and Manthei (1972)

Revegetation trials were established in the summers of 1969, 1970 and 1971 at 11 sites between Fairbanks and Prudhoe Bay, Alaska, along the route of the proposed TransAlaska oil pipeline. The two northernmost sites, in the tundra, had limited growth, but sites in interior Alaska were much more successful. Species rated 'excellent' for revegetation purposes included Arctared creeping red fescue, Nugget Kentucky and Icelandic bluegrasses, Meadow foxtail and Annual ryegrass. Species rated 'good' included an unnamed variety of creeping red fescue (possibly Boreal - H.H.?), Climax and Engmo timothies, Reed canarygrass and Deschampsia caespitosa (hairgrass). Seed mixes were sown in 1971 but thus far, insufficient time has elapsed to evaluate them. Fertilizer usually enhanced plant growth and flowering. Refertilization in the second year proved most beneficial.

Plant establishment was more successful on sites with exposed mineral soil. Seeding on replaced turf resulted in no seedlings establishing on the organic mat itself. However, regrowth from rootstocks in the mat did occur. Thus, in some areas where establishment of seeded species is poor, the best means of revegetation could be from live roots and rhizomes remaining in the organic mat. Transplanting of hardy, 3 year old tree seedlings of white spruce and lodgepole pine proved successful in the interior, as did the transplants of cores of some sedges and cottongrass in tundra areas. Natural invasion on to disturbed sites was similar to that in other areas. Grasses often seeded in and rootstocks of shrubs sprouted.

Relationship to the present study

The results of these studies corroborate the findings of and support conclusions drawn from the present study and others, as presented earlier (see from pg. 169). The creeping red fescues, Arctared and Boreal, Nugget Kentucky bluegrass, Meadow foxtail and Engmo timothy were once again among the successful species, especially in forest areas. Fertilizer stimulated plant growth, as these studies again pointed out the nutrient limitations present in cold arctic soils (Haag, 1972). Re-fertilization in the second year was beneficial for maintaining and stimulating plant growth.

McCown's (1972) study further emphasizes the possible effect that revegetation attempts may have on animal activity and vice versa.

Both McCown (1972) and Van Cleve and Manthei (1972) re-emphasized that mineral soil is best for plant establishment and that mulching or organic mats retard this same establishment, partly because of nutrient deficiencies. Thus, both studies further revealed the dichotomy of possible revegetation strategies. Which is more desirable or successful: (a) Exposure of mineral soil with greater establishment of seeded species - if the increased soil conductivity does not result in melting of sub-surface ice -, or (b) Replacement of the surficial organic mat and regrowth from viable roots and rhizomes - if such restoration is feasible after intensive construction activities?

Table 24. List of common and scientific names of agronomically selected and native species sown in test plots at Norman Wells, Inuvik and Tuktoyaktuk, N.W.T. and Prudhoe Bay, Alaska in 1970, 1971 and/or 1972.

| Common or Variety Name | Scientific Name |
|---|---|
| AGRONOMICALLY SELECTED SPECIES | |
| Perennial Grasses | |
| Canon Canada bluegrass | *Poa compressa* L. |
| Nugget Kentucky bluegrass | *Poa pratensis* L. |
| Polar bromegrass | *Bromus inermis* Leyss. |
| Arctared creeping red fescue | *Festuca rubra* L. coll. |
| Boreal creeping red fescue | *Festuca rubra* L. coll. |
| Meadow foxtail | *Alopecurus pratensis* L. |
| Kall orchardgrass | *Dactylis glomerata* L. |
| Frontier reed canarygrass | *Phalaris arundinacea* L. |
| Imperial reed canarygrass | *Phalaris arundinacea* L. |
| Climax timothy | *Phleum pratense* L. |
| Engmo timothy | *Phleum pratense* L. |
| Fairway crested wheatgrass | *Agropyron cristatum* (L.) Gaertn. |
| Greenleaf pubescent wheatgrass | *Agropyron tricophorum* (Link) Richt. |
| Slender wheatgrass | *Agropyron trachycaulum* (Link) Malte |
| Streambank wheatgrass | *Agropyron riparium* Scribn. & Smith |
| Sawki russian wildrye | *Elymus junceus* Fisch. |
| Cereal Annuals | |
| Pendec Oats | *Avena sativa* L. |
| Frontier Rye | *Secale cereale* L. |
| Legumes | |
| Falcata alfalfa | *Medicago sativa* L. |
| Aurora alsike clover | *Trifolium hybridum* L. |
| Leo birdsfoot trefoil | *Lotus corniculatus* L. |
| NATIVE SPECIES | |
| Grasses | |
| Tall arcticgrass | *Arctagrostis latifolia* (R.Br.) Griseb. |
| Bluejoint | *Calamagrostis canadensis* (Michx.) Beauv. |
| Sedge | |
| Cottongrass | *Eriophorum vaginatum* L. |
| Forbs | |
| Fireweed | *Epilobium angustifolium* L. |
| Marsh fleabane | *Senecio congestus* (R.Br.) DC. |

# HIGH ARCTIC DISTURBANCE STUDIES

by

Thomas A. Babb

## INTRODUCTION

Although the northern islands in the Canadian Arctic have largely been thought of as barren "polar desert", to categorize the entire region as such is misleading. A small but significant portion of the landscape has a closed "tundra" vegetation and thus supports considerable wildlife. Besides affecting forage on land, surface disturbance and terrestrial pollution effects may be felt in other habitats. Watersheds drain ultimately into the Arctic Ocean, a complex of marine systems whose functions are not well known. Freshwater aquatic habitats, an integral part of the landscape, support another unique biota which is indirectly tied to distant regions by way of nesting migratory waterfowl. Surficial disturbance related to oil exploration and transport being inevitable, a study of the immediate effects of overland travel and other activities was warranted. A regional approach, combining intensive surface manipulation experiments and extensive examination of actual instances of disturbance, was needed.

Before the study was begun, applied ecological work in the region was sparse. There were a few local accounts of disturbance (Beschel 1963, Kevan 1971) but most botanical literature was descriptive (Porsild 1964, Savile 1961, 1964, Tedrow 1968 and others). More recently, several other local papers have dealt with effects of recent industrial activities (Barnett and Forbes 1972, Kuc 1972). A report to ALUR and a subsequent M. Sc. Thesis (Babb 1972a, 1972b) describe the earlier portions of this project. Implications of this and the most recent work will be covered here.

During the 1972 field season, fertilization, clipping and diesel fuel spill experiments were continued on Devon Island. New fertilization plots were established on airstrips on Ellef Ringnes and King Christian Islands and on tractor trails on Devon. Aerial and ground reconnaissance on the Fosheim Peninsula, Ellesmere Island, was conducted and has provided further information in disturbance susceptibility in a region where industrial development is likely.

# METHODS

## Fertilization Trials

Plots treated in 1970 with N, P, and K fertilizers (Babb 1972a) were monitored. Growth of Saxifraga oppositifolia and Dryas intergrifolia in beach ridge plots and of Carex stans in the meadow plots were measured. Ten groups of ten mature shoots per species were randomly chosen in each plot (N=30 for 3 replications per treatment). Comparisons of green dry shoot weights (80°C) between treatments and controls were by a 't' test. Flowering of Saxifraga was estimated with each of the plots by 10 random placements of a 10 X 20 cm frame, that of Dryas by counting all of the inflorescences.

## Clipping Experiment

The 1972 experiment was a continuation and repeat of that in 1971 (Babb 1972a). The control plots from 1971 were clipped at biweekly intervals from 23 July to 18 August 1972, and a new set of controls was established. At the beginning and end of the growing season, 20 X 20 X 6 cm sections of turf were removed from replicate treated and control plots. Sedge roots, shoots and rhizomes were separated and immediately preserved for later analysis for starch and sugar contents (Fonda and Bliss, 1966).

## Oil Spills

In addition to plots treated in 1970 with diesel fuel at intensities of .05 and .25 $l/m^2$, beach ridge and meadow plots were treated in 1972 at high intensities of 3 $l/m^2$ spilled on late spring snow. Bacterial plate counts for comparison of microbial population were made by Dr. Widden from soil samples in treated and control plots.

## Reconnaissance: Ellesmere Island

Several days were spent through the courtesy of Mobil Oil in surveying areas of potential disturbance in the Fosheim Peninsula region. After approximately 1,000 miles of aerial observation from 300-600 m, a number of previously established representative areas were visited for detailed descriptions of substrate and vegetation. It was thus possible to relate topography and appearance from the air to variation in plant communities. An impact susceptibility map with a five-point scale of sensitivity was drawn using topographic maps as background reference.

Table 1. The effects of fertilization on plant growth and flowering over a 2 year period on Devon Island. Plots were treated on July 12, 1970. Production data are shoot dry weights expressed as a percent above controls. Flowering data are Flowers/m$^2$. Confidence limits are at the 95% level.

| | | Production (% above controls) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Treatment (kg/ha) | | | | | | | |
| Species | year | N56 | N336 | P56 | P336 | K56 | K336 | NPK56 | NPK336 |
| *Carex stans* | 1971 | -14±9 | 53±20** | 10±18 | 15±13 | -15±10 | 44±20* | 14±23 | 82±28** |
| | 1972 | 5±18 | -21±12 | 8±18 | 2±22 | -20±19 | 63±26* | 30±30 | 65±28** |
| *Saxifraga oppositifolia* | 1971 | 131±42** | 153±44** | 38±17* | 201±54** | 34±17* | 16±16 | 276±60** | 288±42** |
| | 1972 | 128±25** | 129±24** | 29±24 | 60±23** | 24±30 | 60±39* | 110±34** | 207±66** |
| (Flowering) | 1972 | 224 | 13 | 45 | 218 | 60 | 25 | 411 | 391 |
| *Dryas integrifolia* | 1971 | 44±16* | 19±16 | 12±14 | 70±25** | 1±9 | 6±13 | 50±16** | 59±19** |
| | 1972 | 10±11 | 38±40 | -14±9 | 57±30* | -16±13 | 5±10 | 52±26** | 80±40** |
| (Flowering) | 1972 | 11.4 | 1.7 | 8.8 | 16.7 | 8.7 | 4.0 | 18.8 | 12.2 |

* Significantly different from controls at P = 0.95.

**Significantly different from controls at P = 0.99.

## RESULTS AND DISCUSSION

### Fertilization Trials

Continued monitoring of plant production in the Devon Island plots substantiates previous findings. Treatment at low (56 kg/ha) and high (336 kg/ha) intensities with N and P and with combinations of N, P, and K stimulated growth, though at rates lower than in 1971. Flowering in *Saxifraga oppositifolia* and *Dryas integrifolia*, as well as in less important species, was conspicuously stimulated (Table 1). The slight general decrease in production with respect to controls may be attributable to a short, cool growing season in 1972, to decreased levels of available nutrients, or to the re-allocation of carbohydrate reserves from shoot to flower production. It should be expected that nutrients not assimilated shortly after treatment would eventually be immobilized or lost through leaching.

In addition to significant responses to N, P, and combined treatments, *Carex stans* and *Saxifraga oppositifolia* responded significantly to potassium. This is contrary to the opinion expressed earlier that natural potassium levels are sufficient for optimum growth. The possibility of lateral movement of nutrients from adjacent plots treated with N or P has not been eliminated but appears minor.

The large standard errors in the treated plots (Table 1) are attributable to varying responses by individual plants. This was probably due to microsite differences in fertilizer penetration and moisture availablilty. Standard errors in control plots were generally less than 10 per cent of the means and increased variability, therefore, is in itself an indication of growth response.

The long-lasting stimulation of growth and flowering illustrates what may be an exceptional capacity in high arctic systems to conserve nutrients once they become available. Though the marked response to fertilizing has been commented upon many times (Bliss 1971, Savile 1972), mineral nutrition of high arctic plants has not been investigated in detail. Tissue samples of several species at various phenologic stages, and soil samples, have been collected for nutrient analyses. These, in conjunction with growth chamber studies under controlled nutrient regime, will enable a more precise quantification of this conservative capacity.

It should be noted that the response of entire communities has certain implications regarding the use of fertilizers for rehabilitation of disturbed areas. On Devon, *Cerastium alpinum*, a relatively unimportant species in

Table 2. Above-ground production and above and below-ground carbohydrate levels in sedges clipped at bi-weekly intervals in a mesic meadow on Devon Island. Data are means $\pm S_{\bar{x}}$.

| Date | Treatment | Annual Above-ground Production ($g/m^2$) | Total Carbohydrates: Shoots, % dry weight | Total Carbohydrates: Shoots, $g/m^2$ | Total Carbohydrates: Roots & Rhizomes, % dry weight | Total Carbohydrates: Roots & Rhizomes, $g/m^2$ |
|---|---|---|---|---|---|---|
| 25/8/71 | a) clipped at beginning & end of season | $25.2 \pm 2.5$ | -- | -- | -- | -- |
| | b) Clipped bi-weekly | $18.7 \pm 1.4$ * | -- | -- | -- | -- |
| | c) Control | $24.9 \pm 2.7$ | -- | -- | -- | -- |
| 23/7/72 | b) Clipped bi-weekly (1971) | -- | $2.3 \pm 0.3$ | $0.49 \pm 0.06$ | $1.1 \pm 0.2$ | $0.94 \pm 0.17$ |
| | c) Clipped bi-weekly (1972) | -- | $1.6 \pm 0.5$ | $0.34 \pm 0.10$ | $2.6 \pm 0.5$ | $2.22 \pm 0.43$ |
| 16/8/72 | b) Clipped bi-weekly (1971) | $10.3 \pm 0.3$ | $4.9 \pm 2.1$ | $1.06 \pm 0.45$ | $2.0 \pm 0.6$ | $1.71 \pm 0.51$ |
| | c) Clipped bi-weekly (1972) | $12.2 \pm 1.1$ | $6.1 \pm 0.6$ | $1.32 \pm 0.13$ | $2.3 \pm 0.4$ | $1.96 \pm 0.34$ |
| | d) Control | $12.2 \pm 0.5$ | $6.7 \pm 1.9$ | $1.45 \pm 0.41$ | $3.9 \pm 1.3$ | $3.33 \pm 1.11$ |

* Significantly different from controls at P=0.95 in a paired plot arrangement.

undisturbed communities, showed an estimated fifteen-fold increase in biomass following treatment, as compared to 300 per cent and 50 per cent for *Saxifraga oppositifolia* and *Dryas integrifolia* respectively. Heightened competition between vigorously growing minor species and previous dominants (e.g. *Dryas*) could ultimately be a detriment to the latter, and recovery to a "natural" state may be slowed, not hastened, by fertilization. *Dryas* was, in fact, eliminated from an older site where fertilization by a decaying muskox carcass had occurred. Lichens have also been observed to suffer setbacks, perhaps because of allelopathic effects where vascular plant vigour is great. Although such a change would not necessarily be harmful, benefit is not immediately evident in light of effort and expense of treatment, and because high arctic vascular plants play only a minor role, at best, in stabilizing ground surfaces.

## Clipping Experiment (simulated grazing)

In previous reports it was suggested that one year of intense clipping might strongly deplete overwintering carbohydrate reserves so that subsequent yield would be lessened for some time. The repetition of last year's experiment combined with carbohydrate analyses revealed that this is probably not the case. Although at the beginning of the season underground reserves were approximately 50 per cent lower in the previously clipped plots (significantly different from controls at $P = 0.85$), subsequent production was not affected (Table 2). By the end of the season, reserves had at least partially recovered. Plots clipped in 1972 were not significantly affected, partly because of the short duration of treatment (23 July to 18 August), and because sample variability obscured any real differences which may have existed.

## Oil Spills

In the plots treated at high intensity in 1972, all treated vegetation in beach ridge and meadow habitats was killed completely. Although the exact data are not presently available, plate counts of bacteria in soil samples revealed a several-fold increase in bacterial populations within four weeks of treatment in both beach ridge and meadow habitats. Similarly, plate counts made in 1972 from plots treated at low intensity in 1970 revealed bacterial populations slightly higher than controls. Vascular plants are visibly recovering from the 1970 treatments, though recovery is slow and incomplete.

At this stage it appears that the hydrocarbon toxicity to vascular plants is not greatly different from

that studied in much more detail in the Low Arctic (e.g. Wein and Bliss 1973). The effect of diesel fuel (and probably of other hydrocarbon mixtures including crude oil) on photosynthetic tissue is immediate and irreversible. As the fuel disperses by evaporation and in runoff, recovery by surviving plant parts begins, but is slow in accordance with other limiting factors in the High Arctic environment. As in other arctic studies (McCown et al. 1971, Wein and Bliss 1973) breakdown of hydrocarbons by bacteria can occur, but the rate of this process as well is limited by low temperatures.

## Reconnaissance: Ellesmere Island

A map delineating areas on a five-point scale of damage susceptibility is shown (Fig. 1). The scale of sensitivity is as follows (from least to most sensitive):

1. "Polar desert"; bare rock ridgetops, gravel outwash plains, saline plains, fell fields, etc., lacking visible ground-ice features.

2. Similar to 1 in topography and plant cover but showing evidence of horizontally or vertically segregated ground ice (ice wedge cracks or fine soil texture which may indicate below-ground accumulation of horizontal layers).

3. "Semi-desert"; ice features as in 2 but with up to 50 per cent or more mesophytic vascular plant cover.

4. Heath or "upland tundra"; uplands and slopes with favourable moisture conditions for development of continuous *Salix arctica*, *Dryas integrifolia*, or *Cassiope tetragona* cover.

5. Wet meadows and poorly drained lowlands; continuous cover of mosses, sedges and grasses; massive ground ice likely.

A similar approach, relying on descriptions in literature and personal observations in the region, with existing topographic and geological maps as background, will be used to compile a larger sensitivity map of the Archipelago.

## Additional Experiments

Plots on devegetated airstrip surfaces, at oil camps on Ellef Ringnes and King Christian Islands and tractor trails on Devon were treated with mixed N, P, and K to assess


Fig. 1. Impact susceptibility map of the Fosheim Peninsula region, Ellesmere Island, NWT. Areas are delineated in increasing order of sensitivity. 1 = "polar desert"; 2 = "polar desert" with occasional high ground ice; 3 = semi-desert, mesophytic plant cover to 50%; 4 = heath, cover to 100% frequent, but sporadic; 5 = lowland, meadow vegetation.

the practicality of this technique for revegetation. In a sedge meadow site on Devon, old vehicle tracks where natural revegetation has been slow were treated with fertilizer and "Ethrel", a substance which produces ethylene, a plant hormone known to affect tillering in certain rhizomatous species. It is hoped that shoot initiation in conjunction with accelerated production rates will hasten revegetation by species already present (primarily Carex stans). Results of these experiments will not be evident before the 1973 growing season.

## CONCLUSIONS AND RECOMMENDATIONS

Previous work indicates that difficulties resulting from melting of ground ice are generally less severe in the High Arctic than in the Mackenzie Delta region (Babb 1972b). Additional observations, however, have shown that a significant likelihood remains for problems in some localities. Fine-textured soils are likely to be underlain by horizontal ice-rich strata which result in increases in soil moisture and summer softening following even minor disturbance. Because of the permanent scars which appear on such sites during the course of summer activities, examination of subsurface ice conditions at proposed year-round or summer sites is recommended. Several shallow, exploratory borings by hand auger could identify susceptible localities and avoid the operational expense of relocation, particularly at airstrips and supply points.

Fertilization experiments show that growth of vascular plants can be greatly stimulated by application of N, P, and K at rates of approximately 100 kg/ha (lb/acre). The likelihood of practical utility, however, is minor as there are few foreseeable advantages of revegetation by this means. On a short-term basis, revegetation would be too slow to avoid difficulties resulting from thaw.

The clipping experiment shows that, provided subsurface parts remain intact, relatively little permanent damage is likely to follow disruption of above-ground parts of meadow plants. Vegetation on winter roads, for example, even where ground has blown free of snow will probably not be severely harmed. In contrast, very little appears to survive on "tundra" sites (heath or meadows) used to any extent during summer months. Minimizing summer ground travel, particularly incidental travel, is recommended.

The same precautions against land oil spills as would be practiced in the Low Arctic are recommended (diking of bladders, formation of contingency plans at handling points, etc.).

A minimal amount of familiarity with ice conditions and sensitivity of various plant communities would enable regional planning of development operations so that many of the problems encountered in the past could be avoided. It is hoped that the impact sensitivity map and the accompanying text presently being prepared will make this type of information available.

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